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SAT

DEPARTMENT OF PHYSICS

27 February 1978

Mr. Edward E. Bissell  
Chief Engineer for Operations, Code 740.1  
Sounding Rocket Division  
Goddard Space Flight Center  
Greenbelt, Maryland 20771

Reference: Semi-annual status report, NSG 5108  
Reporting period 1 July 1977 - 31 December 1977

Dear Mr Bissell:

Phase I work on the subject contract has been on experiment re-design and re-building of flight hardware destroyed by re-entry without a parachute.

It had been assumed when the current work was proposed that the instrumentation flown on our flight of September 29, 1977 (flight #25.022 UA/US) would be recovered intact and reflown under the present contract. Since, however, the instrumentation was beyond repair we are upgrading all experiments, primarily improving their sensitivity and packaging.

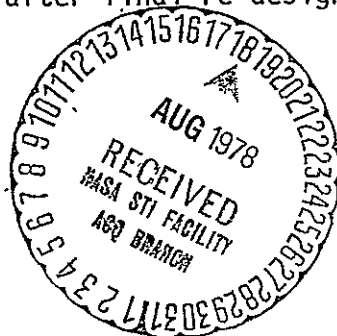
Currently we are well into re-construction of the absolute photon flux photometer. This instrument will measure the absolute solar flux in the neon ionization region ( $\leq 550 \text{ \AA}$ ). Design modifications of the ozone photometer and solar linewidth (helium 584  $\text{\AA}$ ) experiments are still in progress. These experiments will be in fabrication within 60 days.

The electronics will be substantially as flown before, except for mounting changes to facilitate removal of complete experiment packages. Electronic fabrication will be provided by Lockheed Space and Missile System Division, Sunnyvale, California. At this time it is expected that fabrication of electronic boards will begin in April, 1978, following completion of updating all circuit diagrams and artwork.

A flight late this year (1978) is anticipated. A specific launch date will be set after final re-design is complete.

Sincerely yours,

*Darrell L. Judge*  
Darrell L. Judge  
Principal Investigator  
NASA Grant NSG-5108



DLJ:s1

cc: Dr. R. E. Murphy  
Mts. Genevieve Wiseman

N78-34023  
UNCLAS  
G3/92 35788  
1 Jul. 1977  
Semi-Annual Status Report, 1 Jul. 1977  
University of Southern California  
PROPOSED ROCKET  
EXPERIMENTS TO MEASURE THE PROFILE AND  
INTENSITY OF THE SOLAR He1584A RESONANCE  
LINE

In our ongoing sounding rocket program we have to date measured the solar flux and linewidth of the helium resonance line at 584 Å, the absolute solar flux in the neon ionization region, and have flown a prototype ozone photometer as a piggyback experiment. At this time we have had just two flights. The first was completely successful and contained the above solar flux and linewidth experiments. The second flight contained the solar experiments plus the ozone photometer. During this second flight (9/29/77, flight #25.022) electrical noise compromised the mission success. Post flight analysis of the problem was inconclusive since the parachute failed to deploy, leaving the instrumentation badly damaged. Nonetheless, the second flight 584 Å observations were successful but the total flux measured by the neon absorption cell, and the ozone photometer experiment data, will probably not be useful. Analysis of the second flight data is presently underway.

Analysis of the data from the first flight is complete. A paper on the solar 584 Å results has been accepted for publication in the Journal of Geophysical Research. This paper and a preprint on the total flux measurements are given in Appendices I and II.

Strategy for the investigations is as follows:

#### Experiment 1 - Solar 584 Å linewidth experiment

This experiment uses a curve of growth technique. A low resolution monochromator isolates the solar 584 Å line. The monochromator is then filled with helium and the transmitted 584 Å radiation is measured as a function helium pressure. From these data the solar linewidth is determined.

#### Experiment 2 - Total Ionizing Flux ( $\approx 550 - 50 \text{ Å}$ )

An ionization chamber filled with neon absorbs all solar radiation in the ionization region of neon ( $\approx 575 - 50 \text{ Å}$ ). Here the ionization efficiency is 100%, i.e., each photon absorbed forms one ion-electron pair, which is then collected, thus giving an absolute measure of the solar flux in this spectral region.

#### Experiment 3 - Ozone Photometer

The vertical ozone profile will be observed by measuring absorption in the ozone Chappuis band as a function of altitude. The viewing will be along a local tangent to the Earth, observing the ozone attenuation of scattered atmospheric light at the Chappuis band maximum ( $\approx 6000 \text{ Å}$ ). Two nearby channels will measure the much weaker Rayleigh and aerosol extinction.

During the current year we will complete data analysis of our second flight of last September. In addition, we will rebuild the experiments destroyed by the uncontrolled re-entry of that flight. A tentative flight date for the rebuilt payload is October 1978. We thus expect to obtain data late this year on:

- (1) The solar 584 Å linewidth and flux. Evidence for self reversal will be investigated.
- (2) The total ionizing solar flux in the spectral region from  $\approx 575 - 50 \text{ Å}$ .
- (3) The vertical profile of  $\text{O}_3$ .

This program has been delayed because of the loss of the flight experiments. It was anticipated that the package would be recovered intact with only minimal refurbishing. Rebuilding has caused the program to be stretched out and entails extra expense, most of which is being covered by a generous USC subsidy in the form of machine shop support.

#### PHASE II PROGRAM

The Phase II work will begin April 1, 1978. This effort will complete the work begun during Phase I, the currently funded effort, and will cover instrument calibration, spacecraft integration, launch support and data analysis activities.

A copy of the funded proposal which includes both the Phase I & II budgets and statement of work is given in Appendix III. The proposed NASA contribution for the second period is \$39,423. A detailed breakdown is given in the appended proposal.

APPENDIX I

"MEASUREMENT OF THE PROFILE AND INTENSITY  
OF THE SOLAR He I  $\lambda 584 \text{ \AA}$  RESONANCE LINE"

MEASUREMENT OF THE PROFILE AND INTENSITY  
OF THE SOLAR He I  $\lambda 584 \text{ \AA}$  RESONANCE LINE

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### Abstract

The intensity and profile of the helium resonance line at  $584 \text{ \AA}$  from the entire disc of the sun was investigated using a rocket-borne helium-filled spectrometer and a curve of growth technique. The line profile was found to be accurately represented by a gaussian profile with full width at half maximum of  $122 \pm 10 \text{ m \AA}$  while the integrated intensity was measured to be  $(2.6 \pm 1.3) \times 10^9 \text{ photons sec}^{-1} \text{ cm}^{-2}$  at solar activity levels of  $F_{10.7} = 90.8 \times 10^{-22} \text{ m}^{-2} \text{ Hz}^{-1}$  and  $R_z = 27$ . The measured linewidth is in good agreement with previous spectrographic measurements but the integrated intensity is larger than most previous photoelectric measurements. However, the derived line center flux of  $(2.0 \pm 1.0) \times 10^{10} \text{ photons sec}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$  is in good agreement with values inferred from airglow measurements.

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## Introduction

The solar helium resonance line at  $\lambda 584 \text{ \AA}$  in the extreme ultraviolet has recently been the subject of considerable experimental and theoretical work. The intensity and profile of this emission line can be used to study solar line formation mechanisms and the structure of the chromosphere (Milkey et al., 1973; Zirin, 1975; Milkey, 1975; Shine et al., 1975; Jordan, 1975; Hearn, 1969; Athay, 1965). In addition, knowledge of the intensity and line shape are required for interpretation of resonantly scattered helium emissions from planetary atmospheres (Meier and Weller, 1972, 1974; Carlson and Judge, 1974; Kumar and Broadfoot, 1975) and the local interstellar gas (Weller and Meier, 1974; Suzuki et al., 1975). Unfortunately, despite the importance of this line, the intensity and line shape are not well characterized.

There have been many measurements of the intensities of the solar extreme ultraviolet emission lines, including the HeI resonance line, but considerable variance is found among the available data. A related and unresolved problem is found in comparing ionospheric temperatures and densities with the measured solar fluxes. Discrepancies exist which suggest that commonly adopted total flux values (Hinteregger, 1970) may be low by perhaps a factor of two (Swartz and Nisbet, 1972; Roble and Dickinson, 1973).

The profile and width of the solar He line has received less experimental effort than the intensity. A curve-of-growth analysis of the solar line transmitted through varying amounts of terrestrial helium gave only an approximate lower limit to the width:  $\sim 140 \text{ m\AA FWHM}$  when a gaussian line profile was assumed (Carlson, unpublished analysis of

OSO-6 data). Delaboudiniere and Crifo (1975), using a method similar to the present experiment, have found that the line width must be greater than  $110 \text{ m}\text{\AA}$ . The first direct measurements of the profile (Doschek et al., 1974) were obtained photographically at a resolution of  $60 \text{ m}\text{\AA}$  and indicated an approximate gaussian line shape (but with a slightly more flat central region) with a width FWHM -  $140 \pm 15 \text{ m}\text{\AA}$ . Inclusion of atmospheric He absorption would reduce the derived width somewhat. Photographic spectra of a small region of the quiet solar disc by Cushman et al. (1975) show a width (FWHM) of  $80 \text{ m}\text{\AA}$  and  $100 \text{ m}\text{\AA}$  for an active region.

In this work we have taken advantage of the fact that the line of interest is the resonance transition, and is therefore absorbed strongly by helium atoms.. A rocket-borne spectrometer was filled with varying amounts of helium and a curve-of-growth analysis was applied to the intensity variation of the transmitted line. Absolute calibration of the spectrometer and extrapolation to zero pressure allows a determination of the integrated flux in the line.

### Instrumentation

Because the width of the  $584 \text{ \AA}$  line is narrow ( $\sim 0.1 \text{ \AA}$ ) the direct measurement of the line shape with a grating instrument is difficult, requiring very high resolution. The measurement reported here employed a curve-of-growth technique to determine the line shape. The shape of the solar  $584 \text{ \AA}$  line was determined by admitting helium gas into the optical path of a grating spectrometer to obtain the transmission of the solar line as a function of helium pressure in the spectrometer. Briefly, the operation of the experiment was as follows: A low resolution spectrometer was used to isolate the He I  $\lambda 584 \text{ \AA}$  line. With the spectrometer evacuated, the full intensity of the incident line would be transmitted, except for grating losses. As helium was introduced into the spectrometer, initially only the central core was absorbed out. When more helium was admitted into the cell, the wings of the absorption line became optically thick reducing the transmitted intensity. The transmitted radiation approaches zero when the absorption width becomes comparable with the solar line width. The absorption properties of this resonance absorption technique are illustrated in Figure 1 for the maximum and minimum He pressures used in the experiment. It is clear that the present measurements sample the wings of the solar line and is not influenced by telluric absorption.

By measuring the intensity curve as a function of the pressure of the absorbing gas, one can infer the profile of the solar line. Because the exact shape of the curve depends on the shape of the helium line, it is necessary to fit models for the line shape to the data to obtain the profile. It is inherent in this technique that skewness or asymmetries in the line



shape cannot be detected because the technique determines the sum of the absorption at wavelengths symmetric about the line center.

The spectrometer, shown schematically in Figure 2, provided a resolution of approximately  $15 \text{ \AA}$  with a total optical path length of 106 cm. Three discrete-dynode electron multipliers were used to detect radiation from the  $584 \text{ \AA}$  line and also the  $1216 \text{ \AA}$  Lyman  $\alpha$  and OIV  $555 \text{ \AA}$  lines; the Lyman  $\alpha$  data provided a check on solar pointing, while the OIV data was used to correct for the altitude dependence of atmospheric absorption. The principal characteristics of the spectrometer and the three detector channels are shown in Table 1.

A long optical path was used so that the pressure could be low ( $\sim 0.2$  Torr) to reduce the risk of window failure and pressure broadening of the absorption line.

To reduce the effects of outgassing, the instrument was filled with dry nitrogen or was evacuated at all times for one month prior to launch. The instrument was launched in an evacuated condition. A blowoff cover over the entrance was deployed at high altitude after payload separation. Helium was then periodically admitted into the spectrometer and allowed to exhaust slowly through the entrance slit of the spectrometer. In flight, the pressure varied from 0.015 to 0.15 Torr over a typical cycle. This pressure variation corresponds to a variation in line center optical thickness from  $10^4$  to  $10^5$ .

The helium pressure was measured with an ionization gauge using a radioactive source (1 Ci  $\text{Sc}^3\text{H}$ ) as the ionization source, and a digital integrating electrometer. The gauge-electrometer system quantization resolution was  $2.3 \times 10^{-4}$  Torr, while its overall resolution, including noise, was  $3.3 \times 10^{-4}$  Torr (rms). The gauge was linear within the accuracy.

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of measurement for pressures below 2 Torr. Thermistors were used to monitor the spectrometer temperature.

The photon count from the three spectral channels, the pressure, temperature sensors, and status and synchronization data were telemetered digitally every 0.25s at a rate of 1kbps, using on-off modulation of IRIG channel H. This data was acquired, decommutated, and recorded on the ground by use of a minicomputer equipped with a serial-to-parallel converter and magnetic tape cassette.

Calibration of the spectrometer consisted of verification of the wavelength selection, measurement of the absolute efficiency, and calibration of the pressure and temperature sensors.

The absolute calibration was performed using a 0.5 m Seya monochromator, using an internal ion chamber located behind the entrance slit of the flight spectrometer to measure the overall efficiency of the instrument. The monochromator beam used in the calibration was narrow and did not fill the grating, so that all of the incident radiation was focused on the exit slit, except for losses caused by grating inefficiency. By placing a nitrogen-filled, optically-thin ion chamber behind the entrance slit, the total radiation passing into the instrument and falling upon the grating was measured directly. Use of an atomic gas such as argon would have been preferred but was unavailable at the time. The photoionization yield of  $N_2$  at  $584 \text{ \AA}$  is  $\sim 100\%$  (Samson, 1964). The ion chamber was 22.2 cm long, and the pressure was varied from 0.4 to 16 m Torr of nitrogen. By least-squares fitting the expected  $N_2$  absorption curve as a function of pressure to the observed data, the efficiency of the spectrometer was found to be  $(9.42 \pm 0.64) \times 10^{-5}$  counts per photon.

This efficiency includes the blaze and reflectance efficiency of the grating, filter transmittance and the quantum efficiency of the electron multiplier detector of the He I channel. The entrance slit aperture was  $0.34 \text{ cm}^2$ . An absolute measurement of the efficiency for H I and O IV lines was not made. A postflight calibration was not performed since no recover package was included in the payload.

The pressure calibration was performed by comparing the reading of the radiation gauge to the reading of an MKS Baratron differential capacitance manometer sensing the difference between the helium chamber pressure and the pressure at the inlet of a 120 l/s turbopump. The pump was coupled to the entrance slit through a large aperture port. The calibration was found to be linear to pressures at least as high as 2 Torr. The manometer was calibrated by the manufacturer against a McLeod gauge. The data were least-squares fit for pressure reading below 0.8 Torr to derive an offset and slope for the pressure calibration.

Further details of the instrument design and calibration are described in a USC contract report. (Maloy et al., 1975).

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## Results and Discussion

The instrument was launched successfully from White Sands Missile Range aboard an Aerobee 200 rocket on November 27, 1974 at 1101 local standard time. The payload reached an altitude of 297 km. Solar pointing was provided by a SPARCS pointing control. The deployment of the blowoff cover and cycling of the helium pressure system were successful, and the data was recorded in real time using the minicomputer system.

The results obtained from the spectrometer are plotted in Figure 3, which shows the observed modulation of the pressure and helium counting rate. Because of the high altitude, the variation of the O IV counting rate by atmospheric absorption was small ( $\leq 20\%$  over the useful range). Late in the flight, increased noise was observed in the O IV channel, presumably resulting from a buildup of gas pressure in the electron multiplier caused by window leakage. This noise did not prevent the use of the earlier data to determine the atmospheric absorption correction.

A small offset drift, corresponding to about 0.6 pA, or 0.004 Torr, was observed in the digital electrometer used to record the ion current from the helium pressure gauge. The drift is attributed to an increased leakage current with temperature. Correction for this small drift was accomplished by linear interpolation.

If the solar line profile is assumed to be gaussian, with width  $\Delta\lambda_s$ , then the variation of the transmitted intensity with helium pressure (or line center optical depth  $\tau$ ) is

$$S(\tau) = S_0 \frac{2}{\sqrt{\pi} \Delta \lambda_S} \int_0^{\infty} d\lambda e^{-\left(\frac{\lambda - \lambda_0}{\Delta \lambda_S}\right)^2} e^{-\tau \bar{\Phi}(\alpha, \lambda)} \quad (1)$$

where  $\lambda$  is the wavelength,  $\lambda_0$  the center of the line,  $\bar{\Phi}(\alpha, \lambda)$  the Voigt absorption profile of the helium gas in the spectrometer normalized to unity at line center, and  $\alpha = \frac{\Delta \lambda_N}{\Delta \lambda_D}$  is the ratio of natural to doppler line widths.

Since the solar line is much wider than the doppler width,  $\Delta \lambda_D$ , of the gas in the spectrometer, absorption takes place in the Lorentzian wings, in which case, the absorption profile can be approximated as

$$\bar{\Phi}(\lambda, \alpha) = \frac{\alpha \Delta \lambda_D^2}{\sqrt{\pi} (\lambda - \lambda_0)^2} \quad (2)$$

Using this approximation, Eq. 1 can be integrated exactly, giving

$$S(\tau) = S_0 e^{-\frac{\Delta \lambda_D}{\Delta \lambda_S} \left(\frac{4\alpha\tau}{\sqrt{\pi}}\right)^{1/2}} \quad (3)$$

or

$$\ln S(\tau) = \ln S_0 - \frac{\Delta \lambda_D}{\Delta \lambda_S} \left(\frac{4\alpha\tau}{\sqrt{\pi}}\right)^{1/2} \quad (4)$$

The line center optical thickness  $\tau$  depends upon the He volume density  $n$  and path length  $l$  as

$$\tau = nl\sigma_0 \quad (5)$$

$$\sigma_0 = \frac{\pi e^2}{mc} \frac{f}{\sqrt{\pi} \nu_D} = \frac{\pi e^2}{mc^2} \frac{f \lambda^2}{\sqrt{\pi} \Delta \lambda_D} \quad (6)$$

The validity of the above approximation (Eq. 2) was checked using exact values for the Voigt profile. Over the pressure range used in the present

experiment, the errors were found to be  $<0.6\%$ . Consequently, Eq. 4 can be used to accurately determine  $\Delta\lambda_S$ . The variation of the logarithm of transmitted intensity described by Eq. 4 is linear with the square root of pressure (or number density) and is independent of the doppler width of the absorbing gas, as can be verified applying relations (5) and (6) in Eq. 4.

A plot of a sample of data taken from the pressure cycle nearest apogee is shown in Figure 4. The logarithm of the counting rate, corrected for circuit dead time, but not for atmospheric absorption, is plotted against the square root of the gas density. The data are well fit by a straight line.

A more complete analysis was performed using the entire set of data. The atmospheric absorption was accounted for by fitting the logarithm of the  $O\ IV\ \lambda 555\ \text{\AA}$  counting rate to a quartic polynomial in time. This smooth function was then used to normalize the helium counting rate after dead time corrections. The resulting best fit parameters are a line width of  $\Delta\lambda_S = 73.3 \pm 6\ \text{m\AA}$ , or a width (FWHM) of  $2\sqrt{\ln 2}\ \Delta\lambda_S = 122 \pm 10\ \text{m\AA}$ . The present results as well as other determinations of the solar helium line width are presented in Table.2.

It is possible that the solar line is displaced from the helium rest frequency, due perhaps to collisions during emission. In this case, the measured line width would be larger than the true value. We have computed the relationship between the true and measured line widths for various shifts in the solar line. These results are shown in Fig. 5. Note that the derived line width is insensitive to reasonable shifts in the solar line.

The extrapolated count rate at zero pressure, corrected for atmospheric absorption and circuit dead time effects, corresponds to an integrated line flux of  $2.6 \times 10^9$  photons  $\text{sec}^{-1} \text{ cm}^{-2}$ . The major source of possible error in this determination are variations in the photomultiplier response due to atmospheric exposure. Since the electron multipliers were operated in the pulse counting mode, for which gain stability is of lesser importance, and the photoelectric responses of materials in this wavelength region are relatively stable, this effect should be minimized. We estimate the accuracy of the derived results to be  $\pm 50\%$ . The major uncertainty is the long term behavior of the electron multipliers. The resulting integrated line flux at 1 AU is then  $(2.6 \pm 1.3) \times 10^9$  ph/sec/cm<sup>2</sup>. Other recent measurements are listed in Table 3. Note that the present measurement is well within the range of measurements of Hinteregger (1977).

One can determine the line center flux value for the present, and other measurements, using the line width and profile determined above. The present experiment gives  $2.0 \pm 1.0 \times 10^{10}$  ph/sec/cm<sup>2</sup>/Å. The central flux has been inferred from terrestrial and Cytherian helium airglow measurements (Meier and Weller, 1974; Kumar and Broadfoot, 1975) and solar spectrographic measurements (Cushman et al., 1975) with resulting values of  $2 \times 10^{10}$ ,  $1.9 \times 10^{10}$ , and  $1.3 \times 10^{10}$  ph/sec/cm<sup>2</sup>/Å, respectively. It should be noted that the amount of self reversal of the helium line must be quite small since the central intensities inferred from the airglow measurements are among the highest values shown in the figure.

The helium atom resonance scattering rate is calculated from the present results to be  $g = (1.7 \pm 0.8) \times 10^{-5} \text{ sec}^{-1} \text{ atom}^{-1}$  at 1 AU.

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### Acknowledgements

Many people contributed to the success of this program. We would particularly like to thank those at NASA headquarters for their support, as well as the staff at ARC, GSFC, and WSMR: J. Van Ess and the SPARCS groups for their professional support, R. Demorest of GSFC for the vehicle management, and L. Briggs, the U. S. Navy, and the U. S. Army for the launch and recover Operations.

At USC, the success of our effort was assured by the excellent work of the physics shop under B. Poarch, and by the help of Roger Bell, Ralph Caldwell, Audrey Fitzhugh, Neil Hurley, Chung-whei Kao, Elizabeth McCabe, James Repasky, and Chester Sharp.

Time Zero Laboratories of Ball Brothers Research Corporation provided us with circuit board design and fabrication.



TABLE I

Spectrometer and Detector Characteristics

|                        |                                                                                                                       |
|------------------------|-----------------------------------------------------------------------------------------------------------------------|
| Grating:               | Radius - 400.7 mm<br>Blaze Wavelength - 304 Å<br>Spacing - 2400 1/mm<br>Angle of Incidence - 0°<br>Coating - Platinum |
| Entrance Slit:         | Size - 2.5 x 14.1 mm<br>Grating Distance - 801.4 mm                                                                   |
| Resolution:            | 15 Å                                                                                                                  |
| Wavelengths:           | HeI $\lambda$ 584.3 Å<br>O IV $\lambda$ 554.5 Å<br>HI $\lambda$ 1216.7 Å                                              |
| Window Materials:      | Al (2), LiF                                                                                                           |
| Detectors:             | Open BeCu Electron Multipliers<br>Grating Distance - 460 mm                                                           |
| Sensitivity (At 584 Å) | $2.3 \times 10^{-5}$ counts sec <sup>-1</sup> per ph sec <sup>-1</sup> cm <sup>-2</sup>                               |

TABLE II

Various Values Obtained for the Width of the Solar He  $\lambda$  584  $\text{\AA}$  Line

All values are the full width at half maximum.

| <u>AUTHORS</u>                                 | <u>WIDTH (FWHM)</u>              | <u>METHOD</u>                |
|------------------------------------------------|----------------------------------|------------------------------|
| Doschek et al., 1974                           | $140 \pm 15 \text{ m}\text{\AA}$ | Photographic                 |
| Cushman et al., 1975                           | $80 \text{ m}\text{\AA}$         | Photographic                 |
| Carlson, unpublished analysis<br>of OSO-6 data | $\geq 140 \text{ m}\text{\AA}$   | Terrestrial He<br>Absorption |
| Delaboudiniere and Crifo, 1975                 | $> 110 \text{ m}\text{\AA}$      | Curve-of-Growth              |
| Milkey et al., 1973                            | $150 \text{ m}\text{\AA}$        | Theoretical                  |
| Present                                        | $122 \pm 10 \text{ m}\text{\AA}$ | Curve-of-Growth              |

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TABLE III

Integrated Solar HeI  $\lambda 584\text{\AA}$  Line Intensities

| <u>AUTHORS</u>       | <u><math>\Phi [10^9 \text{ ph cm}^{-2} \text{ sec}^{-1}]</math></u> |
|----------------------|---------------------------------------------------------------------|
| Heroux et al. (1974) | 1.28                                                                |
| Higgins (1976)       | 1.47                                                                |
| Schmidtke (1976)     | 1.61                                                                |
| Hinteregger (1977)   | 1.8-2.9                                                             |

FIGURE CAPTIONS

- Fig. 1 Transmitted Solar Helium Line as a Function of Helium Pressure. The lightly shaded area corresponds to the lowest pressure used in the measurements, while the heavily shaded region corresponds to the maximum pressure. Note that the central region which includes telluric absorption is nearly completely absorbed for all pressures used. The present experiment provides a measure of the line shape in the region  $\sim 25\text{m } \text{\AA}$  to  $\sim 50\text{m } \text{\AA}$  from line center.
- Fig. 2 Schematic Representation of the Helium Curve of Growth Spectrometer. High purity helium gas is periodically admitted into the spectrometer to pressure levels of  $\sim 0.2$  Torr. The gas then escapes through the entrance slit. The incident solar helium resonance line is partially absorbed by the 106 cm path length of the gas and passes through Al thin film windows to be detected by open electron multipliers. The variation in transmitted intensity with pressure is used to determine the solar line profile.
- Fig. 3 Variation of the Helium Pressure and Transmitted Intensity during Flight. As the valve is opened and helium admitted into the spectrometer, the solar helium resonance is absorbed. The nearby O IV  $\lambda$  555  $\text{\AA}$  line was also measured, and showed no effect due to admitting the gas into the spectrometer, proving that the absorption is resonance absorption with no effect due to impurity gases. The initial rise of the helium counts after turn on, and the envelope of the curve is due to intervening atmospheric absorption.

Fig. 4     The natural logarithm of the transmitted He 584 Å line intensity as a function of the square root of the helium density in the spectrometer for the measurements obtained at apogee. The line center cross section is  $\sigma_0 = 2.1 \times 10^{-13} \text{ cm}^2$ ,  $l$  is the path length in the spectrometer (106 cm),  $n_v$  the number density, and  $\alpha = 0.007$  the ratio of natural to Doppler widths.  $R_{\text{max}}$  is the maximum observed count rate. Extrapolation to zero pressure gives  $\ln(R/R_{\text{max}}) \simeq 0.33$ .

Fig. 5     Solar Line width as a function of the shift of the line from the helium rest frequency. Note that the derived value is insensitive to reasonable deviations from line center. The solid line corresponds to the best fit to the data while the shaded portion represents the statistical uncertainty.

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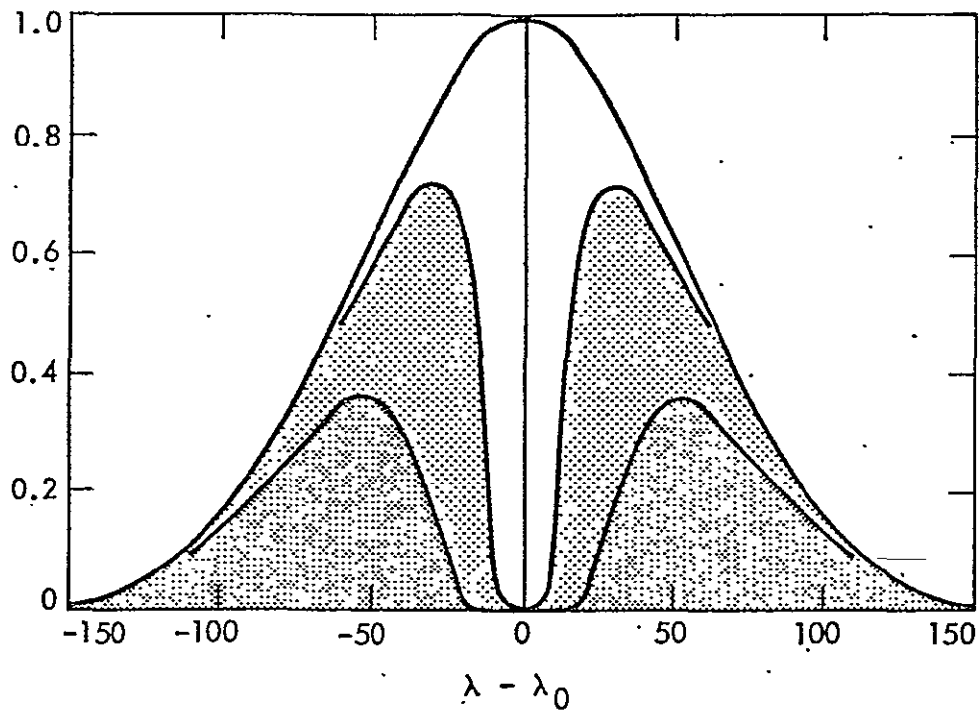


Fig. 1

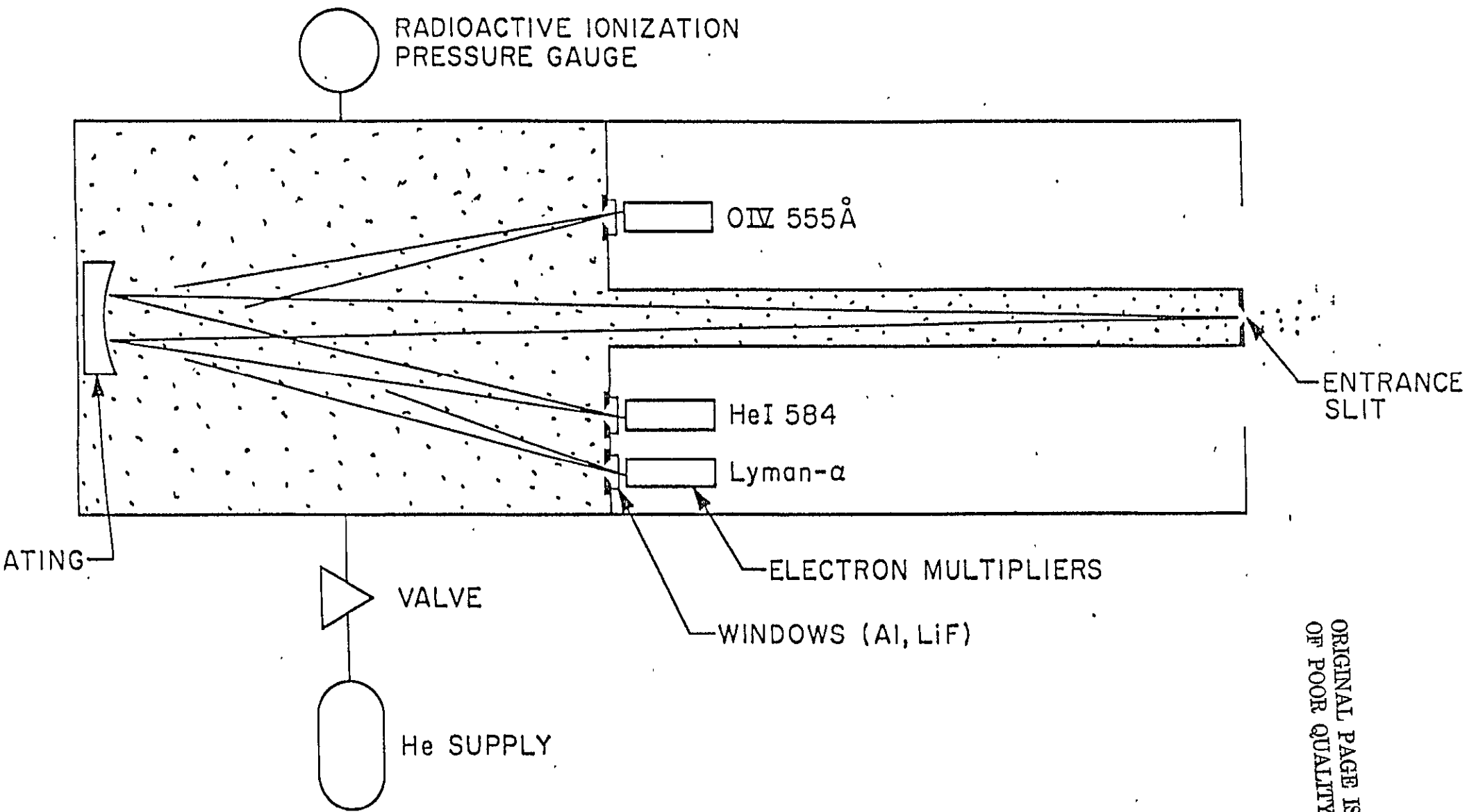


Fig. 2

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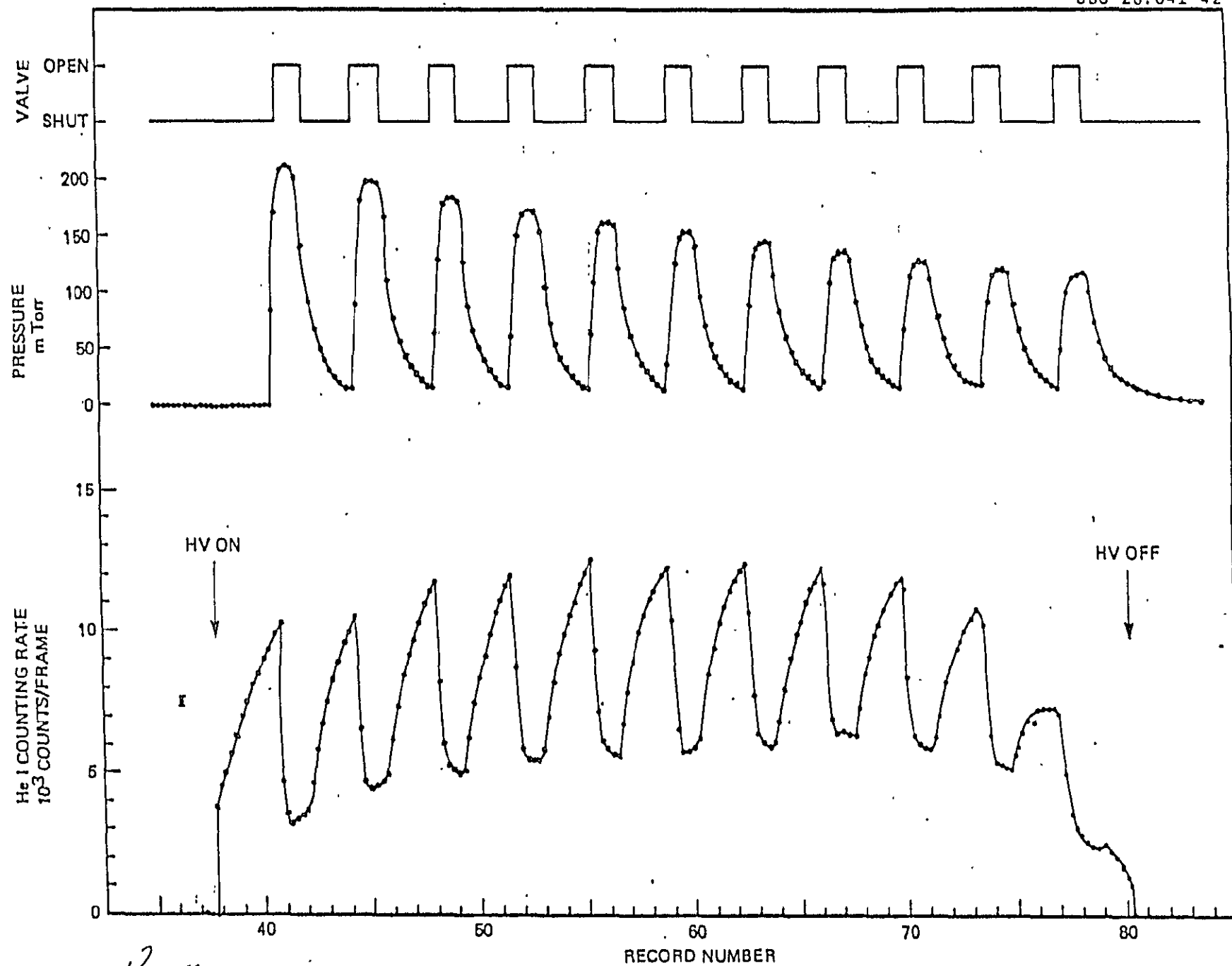


Fig. 3

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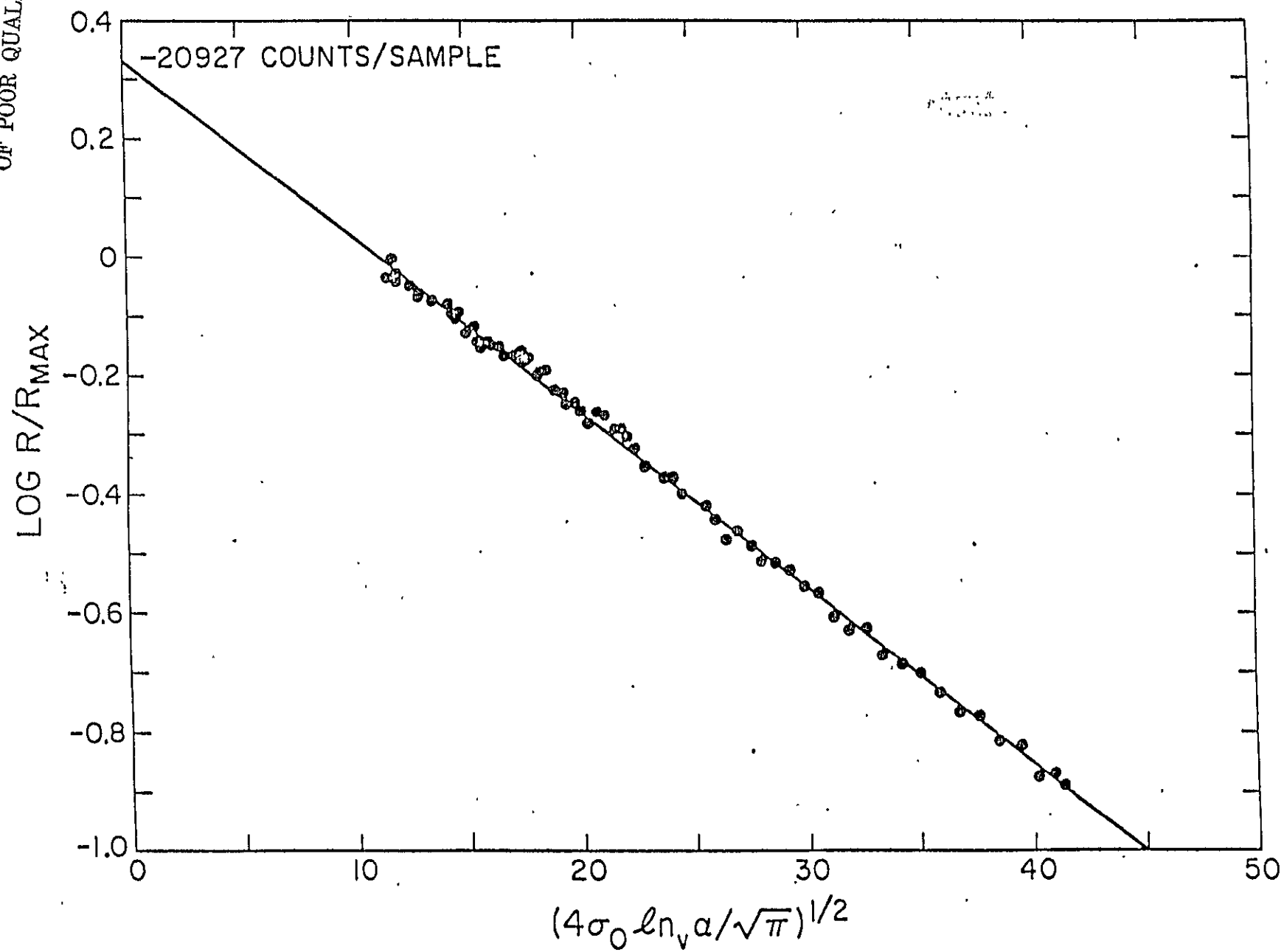


Fig. 4;

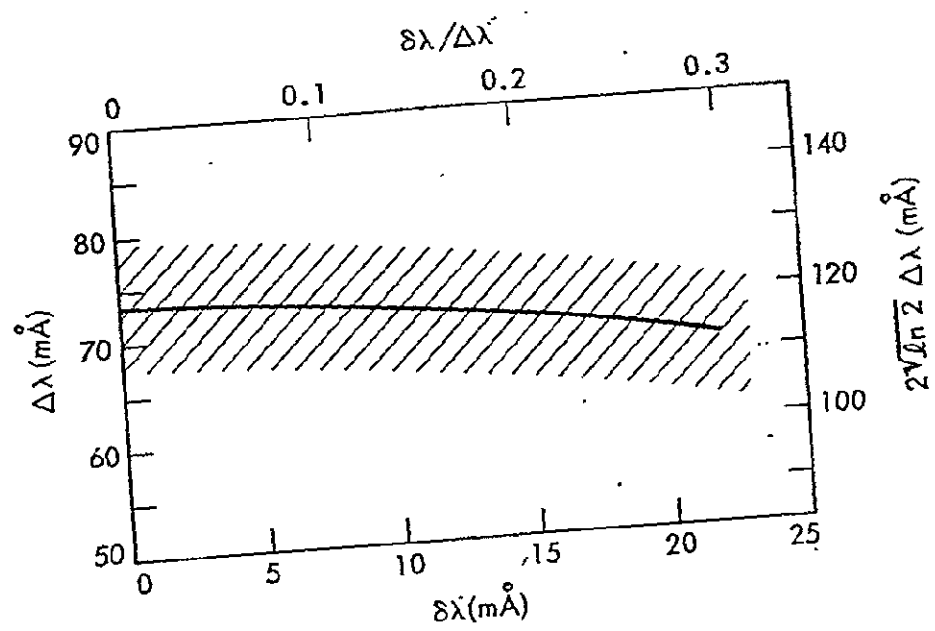


Fig. 5

APPENDIX II

"AN ABSOLUTE MEASUREMENT OF THE SOLAR  
EXTREME ULTRAVIOLET FLUX"

AN ABSOLUTE MEASUREMENT OF THE  
SOLAR EXTREME ULTRAVIOLET FLUX

by

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## ABSTRACT

An absolute detector of extreme ultraviolet radiation was flown on a solar-pointing research rocket to investigate the question of doubling previous measurements of the solar extreme ultraviolet by H. E. Hinteregger. The detector was a windowless total absorption ionization chamber using neon gas, and measured the total solar flux between  $575\text{\AA}^{\circ}$  and  $\approx 50\text{\AA}^{\circ}$ . The value obtained is  $\Phi = 3.7 \times 10^{10}$  photons/sec  $\text{cm}^2 \pm 4\%$  and corresponds to a period of low solar activity ( $F_{10.7} = 90.8$ ). This is a factor of 1.6 greater than Hinteregger's values for medium solar activity. When variations with solar activity are taken into account, a factor of two difference is found, leading to the conclusion that the previous values need to be doubled, at least for the region shortward of  $575\text{\AA}^{\circ}$ .

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There has been some concern expressed recently that the solar ultraviolet fluxes recommended by Hinteregger [1970] are lower than the true values by a factor of two. Swartz [1972] and Swartz and Nisbet [1973] have compared electron densities and temperatures obtained at Arecibo with those implied by Hinteregger's [1970] ultraviolet flux values and found them incompatible. They advanced the hypothesis that the solar flux values were underestimated and should in fact be doubled. Roble and Dickinson [1973] calculated global mean neutral temperatures and electron temperatures using the same solar flux values and also found discrepancies of a factor of two. They considered other energy sources but suggested that a doubling of the solar ultraviolet flux was required to bring the calculated temperatures into agreement with observation.

On the other hand, Prasad and Furman [1974] have examined the necessity for doubling the solar values by investigating electron densities and photoelectron fluxes, finding that the arguments for doubling the ultraviolet flux are not compelling. In addition, Heroux et al. [1974] have made further measurements of the solar flux and compared simultaneously measured ionospheric densities with those inferred from their ultraviolet flux values. These flux values were found to be in substantial agreement ( $\approx 10$ -20%) with Hinteregger's [1970] previous measurements except in the region 450-900<sup>0</sup>Å where some lines were higher than the previous values by 50%. Since the computed electron densities were only 30% less than the measured values, they concluded that a general doubling of the previous values was not warranted.

Despite extensive theoretical arguments for or against the doubling

hypothesis, the question can only be answered by experimental measurements of the solar ultraviolet flux. Unfortunately, spectrometers are difficult to calibrate in the extreme ultraviolet and can suffer additional uncertainties such as degradation of the optical elements and detectors and possible mechanical misalignments introduced during launch. The present experiment is an absolute detector of short wavelength ultraviolet radiation which avoids such problems and was performed in an attempt to investigate the hypothesis that the solar flux values should be doubled at least insofar as the shorter wavelength region is concerned.

## EXPERIMENT DESCRIPTION

The present experiment is a windowless gas ionization cell operated in (near) total absorption using an atomic gas (neon) for which the photo-absorption processes are well-known and readily applied to absolute measurements. The instrument is shown schematically in Fig. 1 and consists of a cylindrical aluminum chamber with a circular aperture of area  $0.0083 \text{ cm}^2 \pm 2\%$  at one end. Neon gas is introduced at a pressure sufficiently high to cause essentially total absorption of radiation with wavelength shorter than the ionization limit of Ne. Since the only continuum absorption process for an atomic gas is photoionization (neglecting the insignificant Rayleigh scattering contribution) and the ionization yield for neon in this wavelength region is unity (except for a small amount of multiple ionization which is discussed below) then if all of the photo ions are collected the resulting ion current gives the ionization rate and thus the flux of sufficiently energetic photons into the instrument.

The ion collection electrode in the present experiment is a 0.48 cm diameter stainless steel rod extending along the length of the ionization cell. A positive potential is applied to the cylinder, forming the electron collection electrode while ions are attracted to the inner rod. Fig. 2 shows the ion collection characteristics of the instrument at a wavelength of  $180\text{\AA}$ . A plateau is found for applied potentials of 10-40V which indicates that all the photo ions are being collected. At higher voltages secondary ionization is produced by accelerated electrons, causing an increase in the ion current. For longer wave-

length radiation, the photoelectrons are initially less energetic and secondary ionization processes occur at higher applied voltages. A collection voltage of 22.0 volts was used in the present experiment. It is possible that some photoelectrons possess enough energy to surmount the applied potential and be collected by the ion electrode. For that reason, this electrode was made small in order to present a small solid angle to the emitted photoelectrons. The relative solid angle is  $\approx 2.5\%$  and roughly 40% of the photoelectrons will be produced with a large enough velocity component to be collected. It is therefore estimated that photoelectron collection is 1% or less of the total. The plateau shown in Fig. 2 supports this contention. The emission of secondary electrons at the ion collection electrode by ion impact has been shown by Gardner and Samson [1974] to be less than 1%. Electron-ion recombination in the gas is quite insignificant since the relatively low ionization rate and fast collection of ions produces a small concentration of charged particles.

The ion current was measured with a high resolution, low noise digital electrometer designed by J. Owen Maloy with an integration period of 0.25 sec. The digitization interval was 0.036pA and the rms noise was observed to be 0.12pA. The electrometer was calibrated using a pico ampere source which in turn was calibrated to 0.5% , and is traceable to the National Bureau of Standards. The standard deviation in the electrometer calibration measurements was 0.7 %.

Neon is a particularly useful gas for ultraviolet ionization chamber measurements. The ionization potential is 21.56 eV ( $575\text{\AA}$ ). The photoionization cross section [Hudson and Keiffer, 1971] is roughly constant in the wavelength region of interest so saturation or near total absorption will occur in approximately the same pressure range for most of solar radiation shortward of the ionization limit. A few autoionizing resonances occur in the ionization continuum [Madden and Codling, 1963] but the amount of solar flux at these wavelengths is negligible and would nevertheless lead to ionization. The onset for double ionization is 62.6 eV ( $198\text{\AA}$ ), and neon does show a small amount of double ionization at higher energies. The cross section is small however, resulting in an increase in the ionization yield of only 3% at  $150\text{\AA}$  [Samson and Haddad, 1974]. From Samson and Haddad's measurements and using a representative solar flux distribution [Heroux et al., 1974], the total correction for double ionization is found to be a 0.7% decrease and estimated to be correct to  $\pm 0.3\%$ . The possibility of simultaneous ionization and excitation by photoionization of an inner 2s electron must also be considered. This process leaves the ion in an excited state which can produce further ionization, either through inelastic collisions (Penning ionization) or by emission of an ionizing photon ( $\lambda = 462\text{\AA}$ ). The threshold for this process is 48.4 eV ( $256\text{\AA}$ ). Wuilleumier and Krause [1974] and Samson and Gardner [1974] have measured the ratios for 2s and 2p photoionization. At  $243\text{\AA}$  the s to p ratio is 2.1% and increases with energy, becoming 12% at  $209\text{\AA}$ . These measurements, in conjunction with the solar flux distribution of Heroux et al. [1974], lead to a  $(-2.4 \pm 1.1)\%$  correction for the simultaneous ionization and excitation process.

Research grade neon was used in the present experiment. The major impurity was He (14.2 ppm) with any remaining impurities  $< 1$  ppm. The neon pressure was varied during the flight in 30 sec. cycles during which time the solenoid valve (see Fig 1.) was open for 10 sec. When the valve opened the ionization chamber pressure rose to  $\approx 1.5$  Torr, decreasing exponentially to  $\approx 0.5$  Torr in 10 sec. by effusion through the entrance aperture. The valve was then closed and the pressure decreased with a time constant of  $\approx 2.5$  sec. Effusion through the entrance aperture is sufficiently slow that external preabsorption by the escaping gas is negligible, amounting to  $\approx 0.5\%$ . At the high pressure limit, the optical depth of the gas is sufficient to absorb  $> 99\%$  of the radiation between threshold and  $180\text{\AA}$  which accounts for  $\approx 90\%$  of the total solar flux below  $575\text{\AA}$ . Absorption at shorter wavelengths is somewhat less, but the net result is that  $> 97\%$  of the flux in the  $50\text{\AA} - 575\text{\AA}$  region is absorbed. This high pressure saturation or near total absorption is demonstrated in Fig. 3. Below  $\approx 50\text{\AA}$  the ion chamber becomes insensitive due to the decreasing neon absorption cross section.

## RESULTS

The experiment was launched on an Aerobee 200 research rocket NASA 26.041 US/UA on 27 Nov 1974 at 18<sup>h</sup>00<sup>m</sup> UT (11<sup>h</sup>00<sup>m</sup> LST) from White Sands Missile Range, and attained a peak altitude of 295 km. An Ames Research Center SPARCS pointing control oriented the payload toward the sun. The solar zenith angle was 55°. A total of eleven pressure cycles were recorded. Results obtained just after apogee are shown in Fig. 3. A slowly varying ionospheric component of  $\approx 15\%$  relative magnitude was observed and subtracted from the raw data.

The 10.7 cm radio flux on the day of the flight was  $F_{10.7}=90.8$  in the customary units while the Zurich sunspot number was  $R_z=27$ . The local exospheric temperature calculated from Jacchia's [1971] formulation was  $T=839^\circ\text{K}$  and the observed altitude variation is in good agreement with densities predicted by Jacchia's [1971] model. At apogee the slant path optical thickness is calculated to be 0.021 with uncertainties in the absorption cross section for atomic oxygen and the atmospheric model introducing an estimated error of  $\pm 0.007$ .

The plateau saturation current obtained from the measurements at apogee is  $47.5 \pm 0.5$  pA. Applying the minor corrections mentioned above (which are summarized in Table 1) and normalizing to 1 AU, the resulting solar flux in the 50-575 Å is found to be  $3.7 \times 10^{10}$  photons/sec-cm<sup>2</sup> with a possible error of  $\pm 4\%$ .

## DISCUSSION

The present measurements, which were obtained during a period of low solar activity, are a factor of 1.6 higher than Hinteregger's [1970] values for medium solar activity, and therefore tend to support the doubling hypothesis. It may be premature to make a more detailed comparison on the basis of a single flight which investigates a more limited spectral region and was performed at a different level of solar activity. However, the spectral region investigated here contains  $\approx 70\%$  of the solar flux which produces the ionospheric F-region and further the variation of short wavelength flux with solar activity (specifically, the 10.7 cm radio flux) has been investigated [Chapman and Neupert, 1974] and an extrapolation can be performed with some confidence. The results are shown in Fig. 4 along with the flux measurements of Heroux et al. [1974], Hinteregger [1970], and Timothy et al. [1972]. The solid line shown in Fig. 4 is from the regression analysis of Chapman and Neupert [1974] (their Table 5) reexpressed in terms of photons/sec-cm<sup>2</sup> and normalized to the present data. It can be seen that for medium solar activity these results give a solar flux approximately twice Hinteregger's value. It is concluded that the hypothesis is correct and the values recommended by Hinteregger should be doubled, at least for wavelengths less than 5750 Å.



## ACKNOWLEDGEMENT

It is a pleasure to acknowledge the many contributions of Drs. J. Owen Maloy and Ulli Hartmann of USC and J. Van Ess and the NASA Ames Research Center SPARCS group for excellent support and flawless solar pointing. This work was supported under NASA contract NAS2-6558 with the Ames Research Center.

Table 1. Ion Chamber Parameters, Corrections, and Associated Errors

|                                                           |                        |        |
|-----------------------------------------------------------|------------------------|--------|
| Entrance area                                             | 0.0083 cm <sup>2</sup> | ± 2%   |
| Correction for preabsorption                              | 1.005                  | ± 0.3% |
| Correction for double ionization                          | 0.993                  | ± 0.3% |
| Correction for simultaneous<br>ionization and excitation  | 0.976                  | ± 1%   |
| Photoelectron collection                                  | -                      | ± 1%   |
| Secondary electron emission                               | -                      | ± 1%   |
| Electrometer calibration                                  | -                      | 0.7%   |
| Picoampere source accuracy                                | -                      | 0.5%   |
| Plateau current measurement                               |                        | ± 1%   |
| Correction to top of atmosphere                           | 1.021                  | ± 0.7% |
| Correction to 1AU                                         | 1.027                  | -      |
| Resulting Flux (10 <sup>10</sup> ph/sec/cm <sup>2</sup> ) | 3.7                    | < ± 4% |

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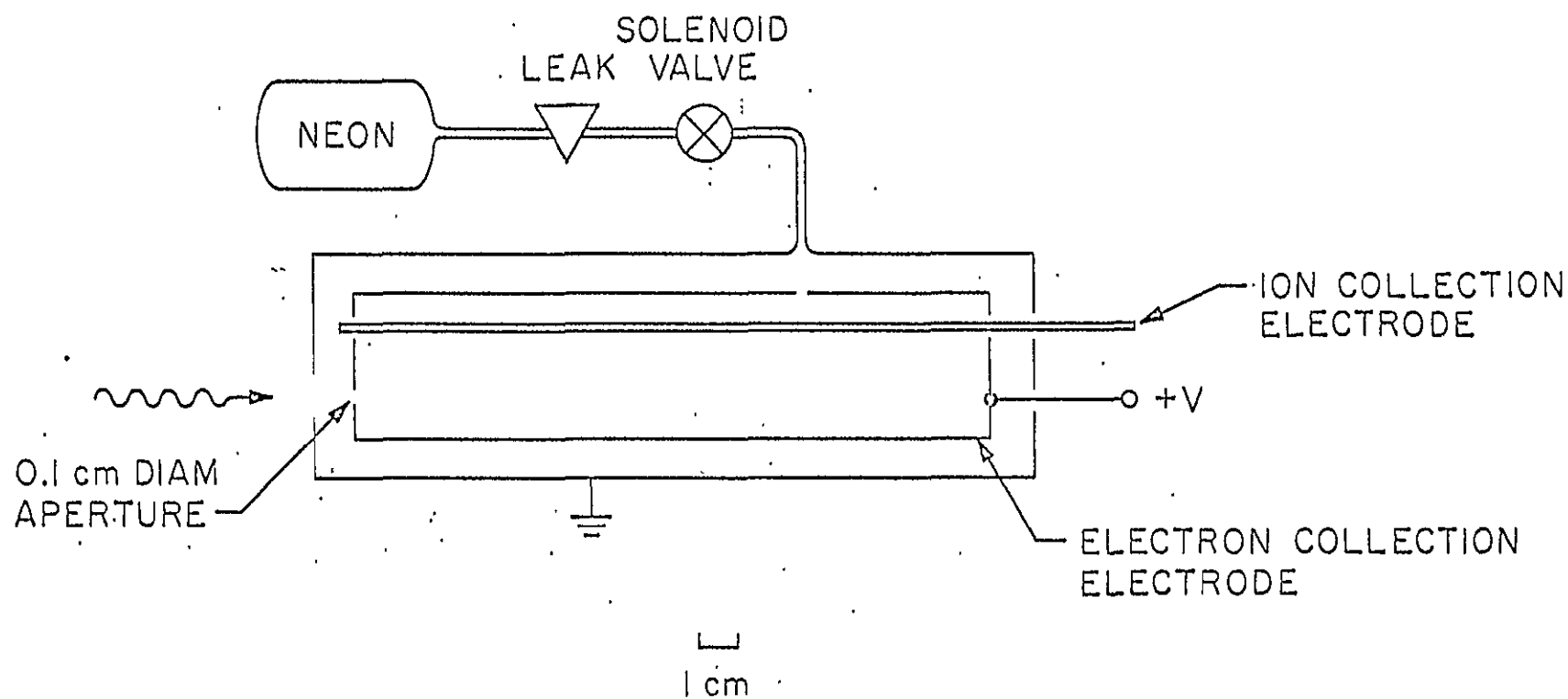
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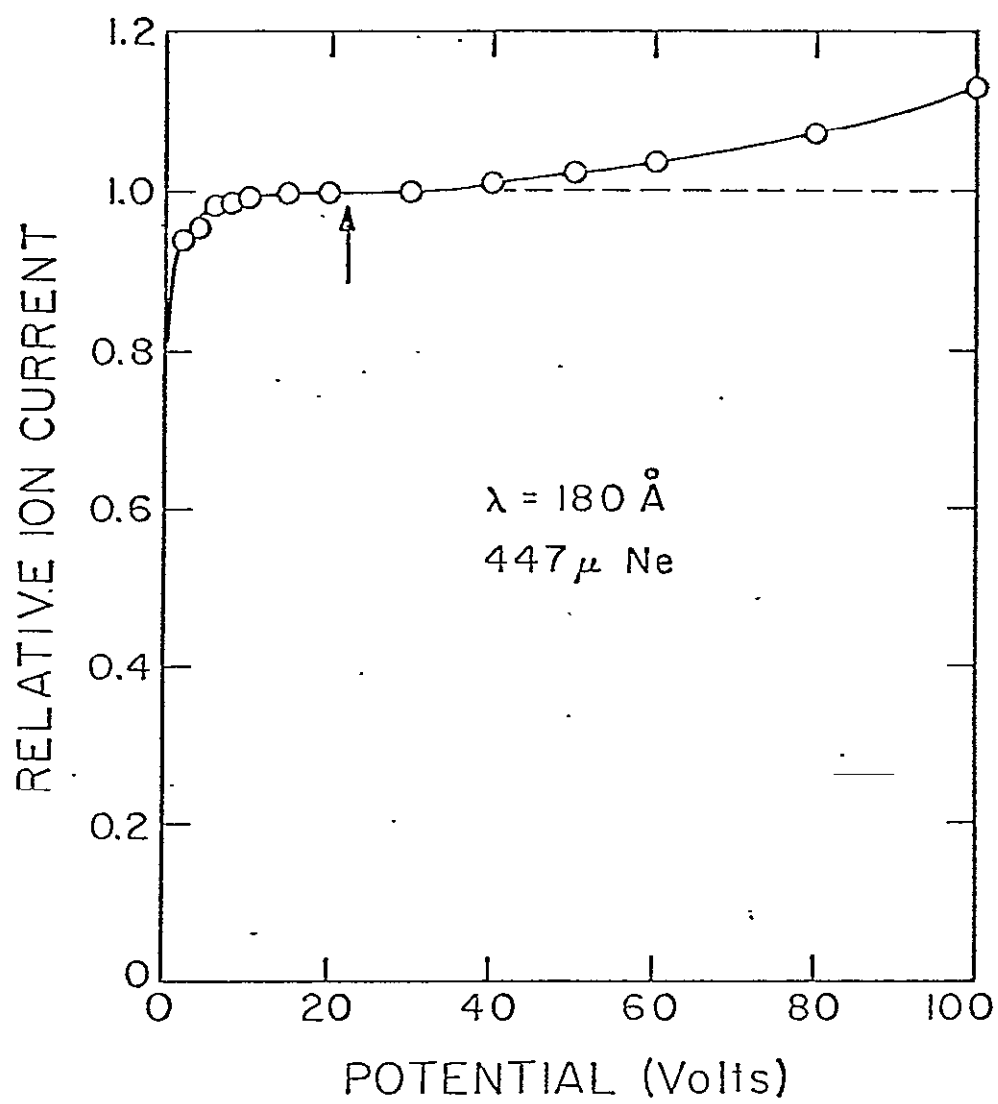
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## FIGURE CAPTIONS

- Fig. 1. Schematic diagram of the ionization chamber. The chamber is filled with neon gas at a maximum pressure of  $\approx 1.5$  torr. The gas then escapes by effusion through the entrance aperture. Radiation enters the chamber, ionizing the gas, and the ions are collected by an electrode and measured with a digital electrometer. The neon supply was a 40cc stainless steel bottle initially filled at 38 psig. The leak consisted of a 64 cm length of 0.1mm ID stainless steel tubing.
- Fig. 2. Ion collection characteristics of the ionization chamber. The measurements were obtained at the University of Wisconsin Synchrotron Radiation Center with an incident wavelength of  $180\overset{\circ}{\text{\AA}}$  and a neon pressure of 0.447 torr. The plateau in the 10-40 volt region indicates 100% efficiency in ion collection. At higher voltages secondary ionization occurs by the accelerated electrons. A voltage of 22.0 volts (indicated by arrow) was used during flight.
- Fig. 3. Ion current measurements obtained by solar irradiation at an altitude of 290 km. The plateau ion current is  $47.5 \pm 0.5$  pA. The absorption cross section of Ne varies between 6 and  $9 \times 10^{-18}$  cm<sup>2</sup> in the wavelength interval 180- $575\overset{\circ}{\text{\AA}}$ ). Theoretical curves are shown for these two cross sections.
- Fig. 4. Comparison of measured values of the total solar flux in the  $50\overset{\circ}{\text{\AA}}$ - $575\overset{\circ}{\text{\AA}}$  region with solar radio activity at 10.7 cm.

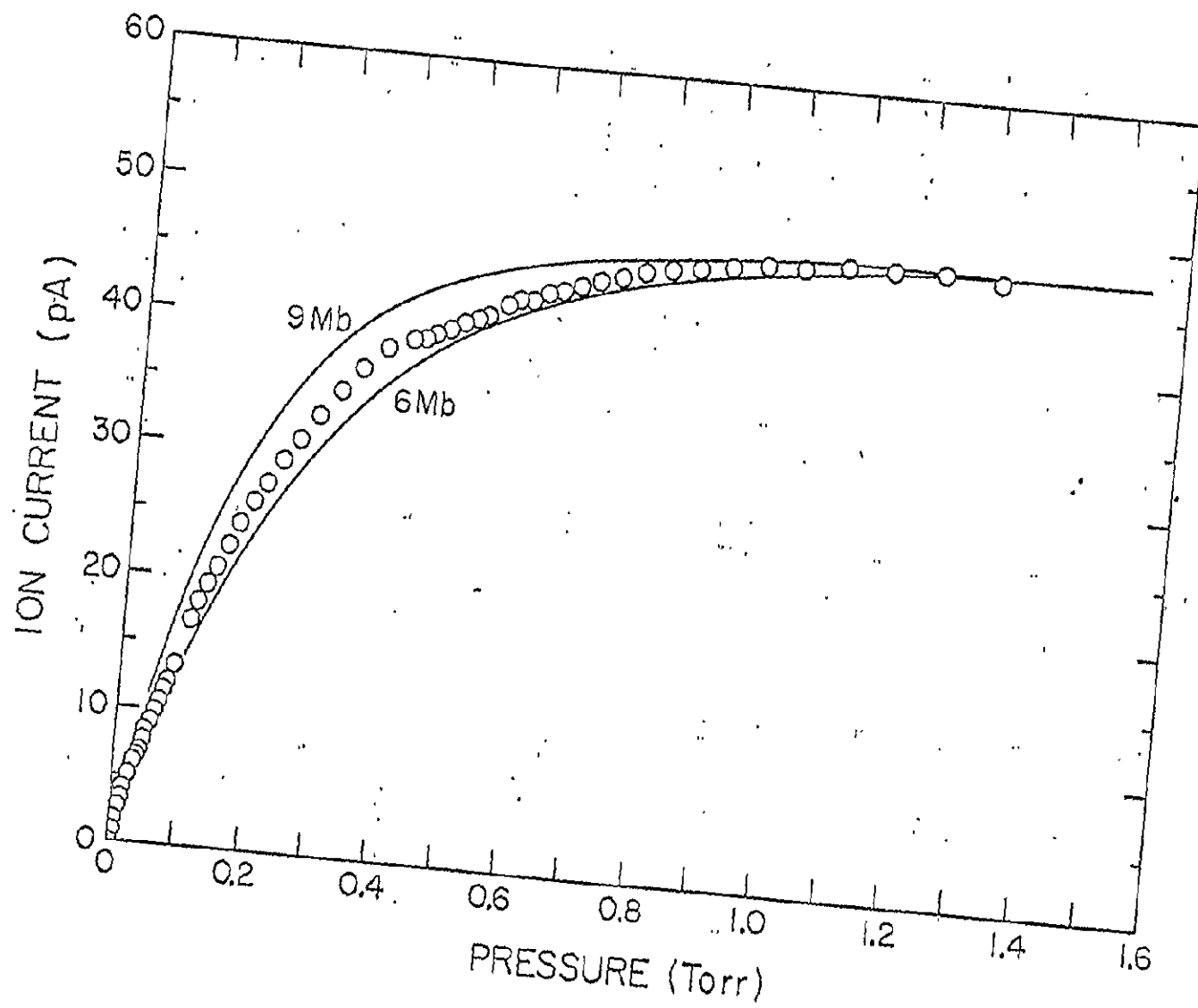
- A: Present Measurements.      B: Heroux et al. [1974]  
C: Hinteregger [1970]      D: Timothy et al. [1972]  
E: Variation of the solar ultraviolet with the 10.7 cm flux  
obtained from the regression analysis of Chapman and  
Neupert [1974], and re-expressed as a photon flux and  
normalized to the present measurements.

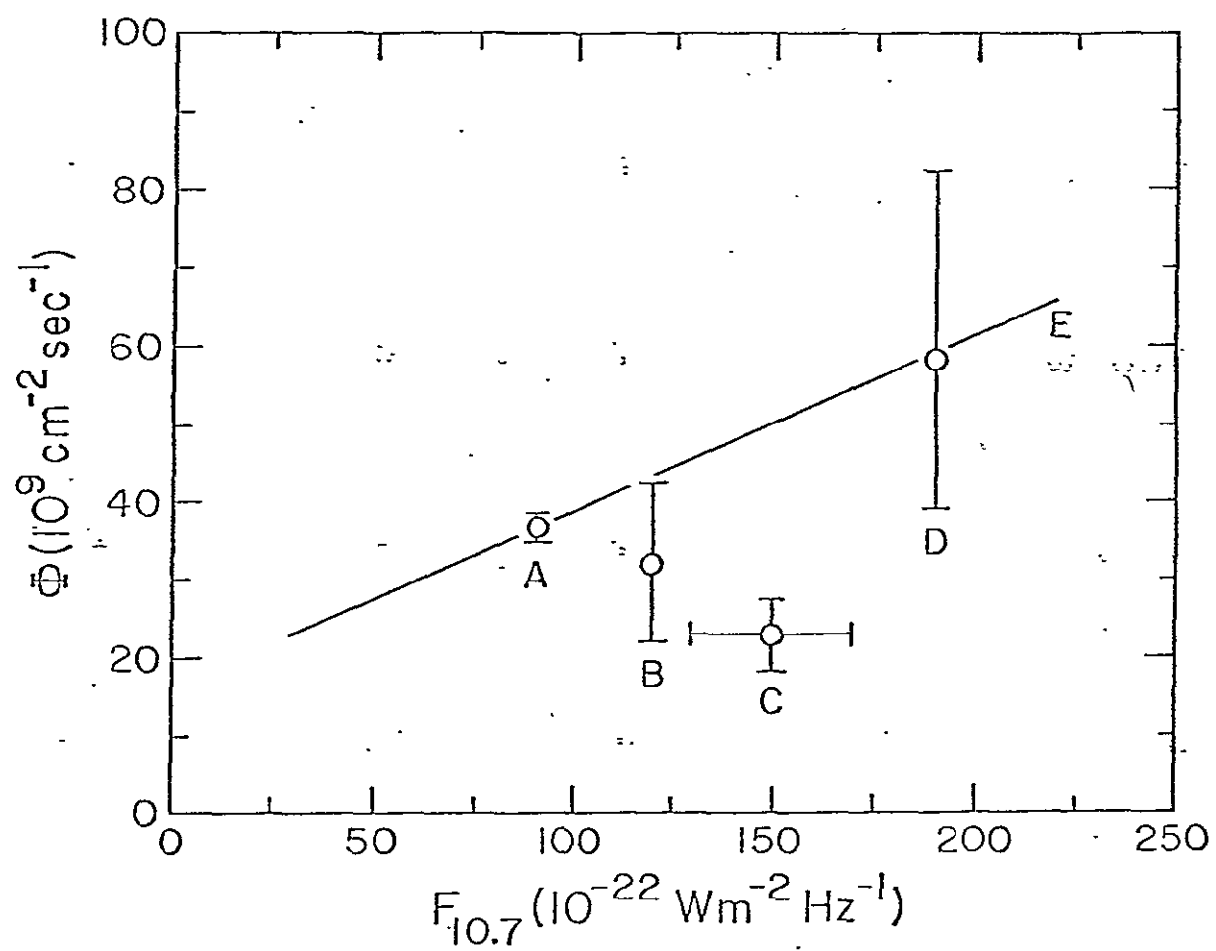






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APPENDIX III  
FUNDED PROPOSAL

PROPOSED ROCKET EXPERIMENTS  
TO MEASURE THE PROFILE AND INTENSITY  
OF THE SOLAR HeI  $\lambda$  584 $\text{\AA}$  RESONANCE LINE

by

R. W. Carlson and D. L. Judge  
Department of Physics  
University of Southern California  
Los Angeles, California 90007

1 March 1977

PROPOSED ROCKET EXPERIMENTS  
TO MEASURE THE PROFILE AND INTENSITY  
OF THE SOLAR  $\text{HeI}\lambda 584 \text{ \AA}$  RESONANCE LINE  
(Continuation Proposal)

by

R. W. Carlson and D. L. Judge  
Department of Physics  
University of Southern California  
Los Angeles, California 90007

Endorsements:

|            | Principal Investigator      | Department Head                            | Institutional<br>Administrative Official |
|------------|-----------------------------|--------------------------------------------|------------------------------------------|
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| Signature: | <u></u>                     | <u></u>                                    | <u></u>                                  |
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## FORWARD

At the request of NASA we changed from an Aerobee rocket to an Astrobee F to conserve the remaining Aerobees, which are being refitted for recovery. The redesign required to accommodate this change necessitated a somewhat longer integration period than previously scheduled. The presently proposed Phase I budget will cover the cost incurred during the extended integration period as well as construction of the presently proposed experiments. The Phase II budget will cover final integration, launch support, and data analysis.

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## 1. STATEMENT OF WORK

We propose to continue our solar and atmospheric research sounding rocket program by investigating

- 1) the absolute value of the solar ionizing flux using an inherently absolute and stable detector--the rare gas ionization chamber, and
- 2) the vertical ozone distribution using limb scans in the ozone chappuis bands.

The following two sections discuss these experiments in turn, providing the scientific background and justification and giving details of the instrumentation.

A solar pointing Aerobee 350 with a standard recovery package rocket is requested.



## 2. ABSOLUTE SOLAR ULTRAVIOLET FLUX MEASUREMENTS

### Scientific Justification

The major purpose of the proposed experiment is to measure the flux of ionizing solar radiation and to relate these values to geophysical observations such as ionospheric densities, electron temperatures, and neutral thermospheric temperatures. With these data, accurate heating rates and thermal conductivities can be obtained. The wavelength interval covered by the present instrument contains >75% of the energy which forms the ionospheric F-region and more than 90% of the energy which heats the thermosphere. The wavelength interval is shown in Fig. 2-1 along with the solar ultraviolet spectral flux distribution averaged over 100 Å intervals.

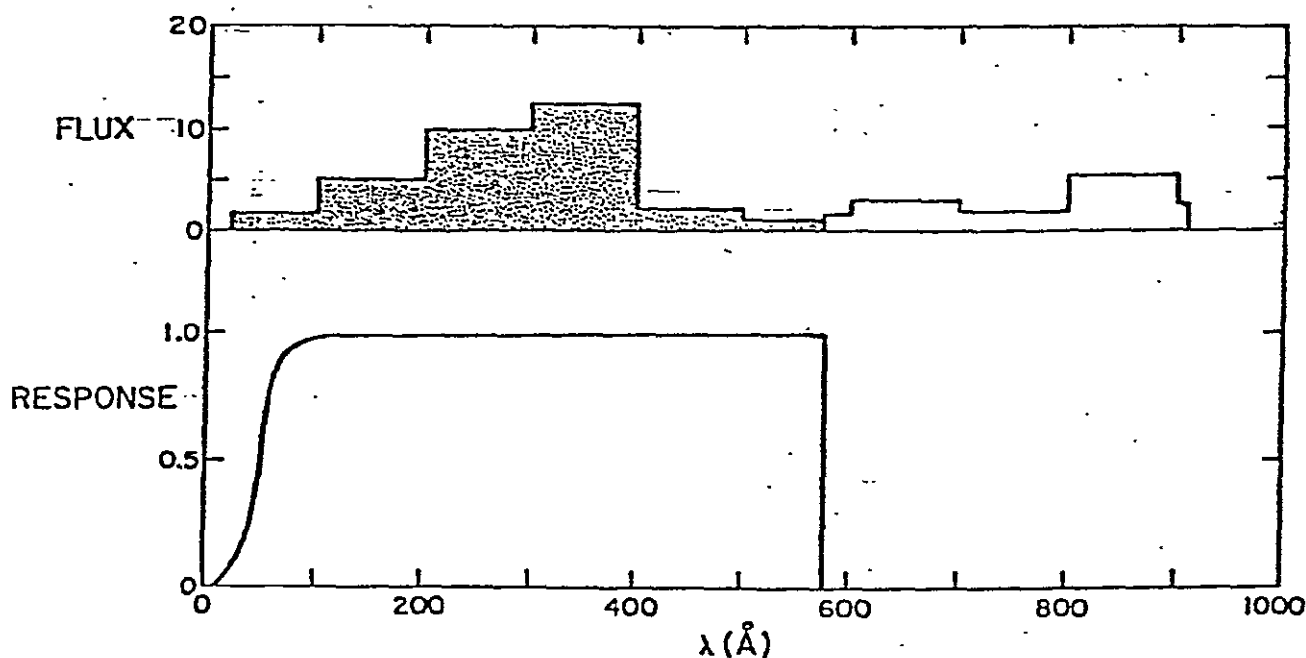


Fig. 2-1. The absolute response of the neon photoionization chamber (lower) and the solar ultraviolet flux ( $\lambda < 910$  Å) averaged over 100 Å intervals.

Despite years of experimental and theoretical work, there is far from complete understanding of solar-terrestrial relations. Indeed, there has been considerable concern expressed recently that the widely used solar ultraviolet fluxes recommended by Hinteregger (1970) are lower than the true values by a factor of two. Swartz (1972) and Swartz and Nisbet (1973) have compared electron densities and temperatures obtained at Arecibo with those implied by Hinteregger's (1970) ultraviolet flux values and found them

incompatible. They advanced the hypothesis that the solar flux values were underestimated and should in fact be doubled. Roble and Dickinson (1973) calculated global mean neutral temperatures and electron temperatures using the same solar flux values and also found discrepancies of a factor of two. They considered other energy sources but suggested that a doubling of the solar ultraviolet flux was required to bring the calculated temperatures into agreement with observation.

On the other hand, Prasad and Furman (1974) have examined the necessity for doubling the solar values by investigating electron densities and photoelectron fluxes, finding that the arguments for doubling the ultraviolet flux are not compelling. In addition, Heroux et al. (1974) have made further measurements of the solar flux and compared simultaneously measured ionospheric densities with those inferred from their ultraviolet flux values. These flux values were found to be in substantial agreement ( $\approx 10$ -20%) with Hinteregger's (1970) previous measurements except in the region 450-900 Å where some lines were higher than the previous values by 50%. Since the computed electron densities were only 30% less than the measured values, they concluded that a general doubling of the previous values was not warranted.

Despite extensive theoretical arguments for or against the doubling hypothesis, the question can only be answered by experimental measurements of the solar ultraviolet flux. Unfortunately, spectrometers are difficult to calibrate in the extreme ultraviolet and can suffer additional uncertainties such as degradation of the optical elements and detectors and possible mechanical misalignments introduced during launch. The present experiment is an absolute detector of short-wavelength ultraviolet radiation which avoids such problems and can be used to resolve the hypothesis that the solar flux values should be doubled.

### The Rare Gas Ionization Chamber

Ionization chambers have been used for absolute measurements in the laboratory for some time and presently constitute the standard detector for absolute calibration in the extreme ultraviolet at the National Bureau of Standards. The operation of these detectors can be described with reference to Fig. 2-2, which portrays an ionization cell flown in November, 1974 on an Aerobee sounding rocket to measure the solar ultraviolet flux.

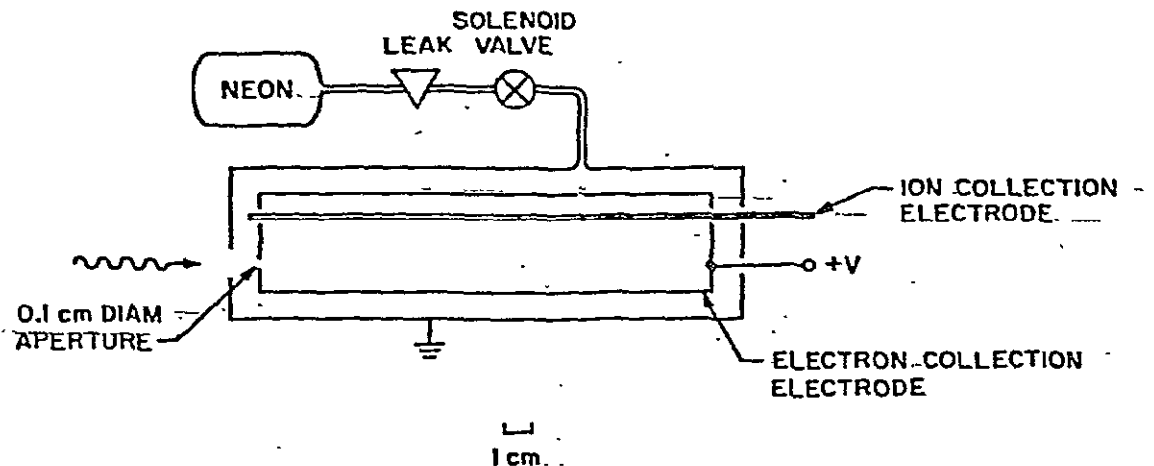
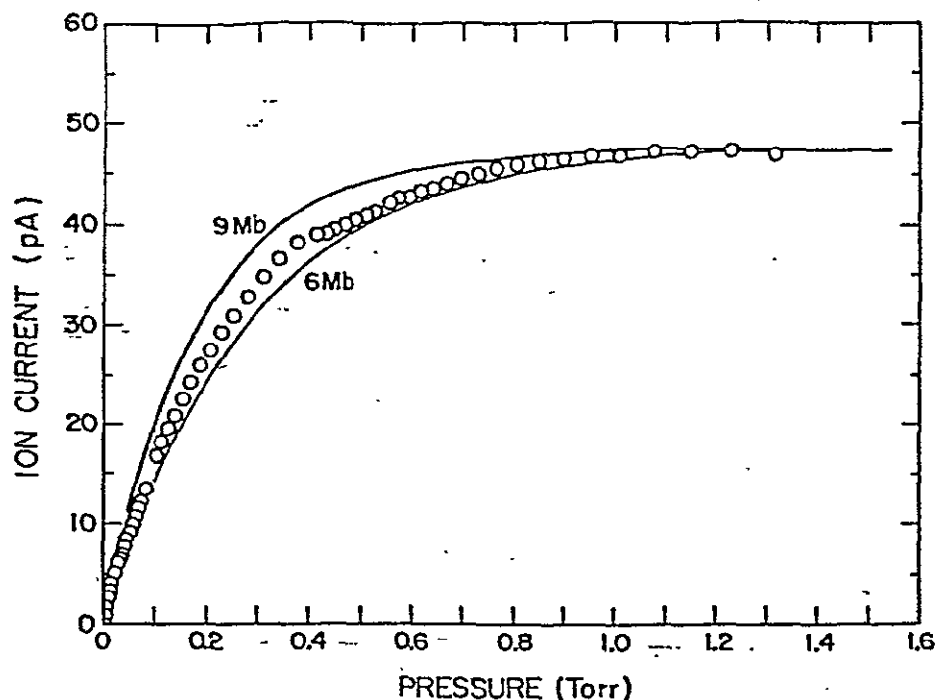


Fig. 2-2. Schematic diagram of the ionization chamber. The chamber is filled with neon gas at a maximum pressure of  $\approx 1.5$  torr. The gas then escapes by effusion through the entrance aperture. Radiation enters the chamber, ionizing the gas, and the ions are collected by an electrode and measured with a digital electrometer.

The chamber is filled with gas at pressures sufficient to cause nearly complete absorption of the ionizing radiation which enters through the small entrance aperture. The walls of the cell are biased to collect electrons, the photo-ions produced in the gas are collected with a small diameter electrode. As the pressure in the cell varies during the fill and vent cycle, a plateau in the ion current is found at high pressure which demonstrates saturation or near total absorption of the flux shortward of the ionization limit. An example of this is shown in Fig. 2-3.

The potential difference between the ion and electron collection electrodes must be sufficient to collect all of the ions and repel photoelectrons, but not so high as to cause secondary ionization by accelerated electrons. The ion electrode must also exhibit a small cross section so that more energetic photoelectrons are not collected along with the ions. Fig. 2-4 shows the ion collection characteristics of the rocket ion chamber for an incident



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Fig. 2-3. Ion current measurements obtained by solar irradiation at an altitude of 290 km. The plateau ion current is  $47.5 \pm 0.5$  pA. The absorption cross section of Ne varies between  $6$  and  $9 \times 10^{-18}$  cm<sup>2</sup> in the wavelength interval 180-575 Å. Theoretical curves are shown for these two cross sections.

wavelength of 180 Å. A plateau is found for applied potentials of 10-40 V which indicates that all of the photo-ions are being collected and that the response of the instrument is independent of bias voltage changes. At higher voltages secondary ionization is produced by accelerated electrons, causing an increase in the ion current. For longer wavelength radiation, the photoelectrons are initially less energetic and secondary ionization processes occur at even higher applied voltages.

Neon is a particularly useful gas for solar flux measurements since it is an atomic gas and therefore the only continuum absorption process is photoionization and the ionization yield in this wavelength region is unity (except for a small amount of double ionization which will be discussed later). The ionization potential of Ne is 21.56 eV (575 Å). The photoionization cross-section (Hudson and Kieffer, 1971) is roughly constant in the wavelength region of interest so saturation or near total absorption will occur in approximately the same pressure range for most of solar radiation shortward of the ionization limit. A few autoionizing resonances occur in the ionization continuum (Madden and Codling, 1963) but the amount of solar flux at these wavelengths is negligible and would nevertheless lead to ionization. The wavelength interval for neon ionization is 50-575 Å and is a particularly significant region for study of the solar chromosphere and the terrestrial atmosphere and ionosphere. These aspects are discussed in the following.

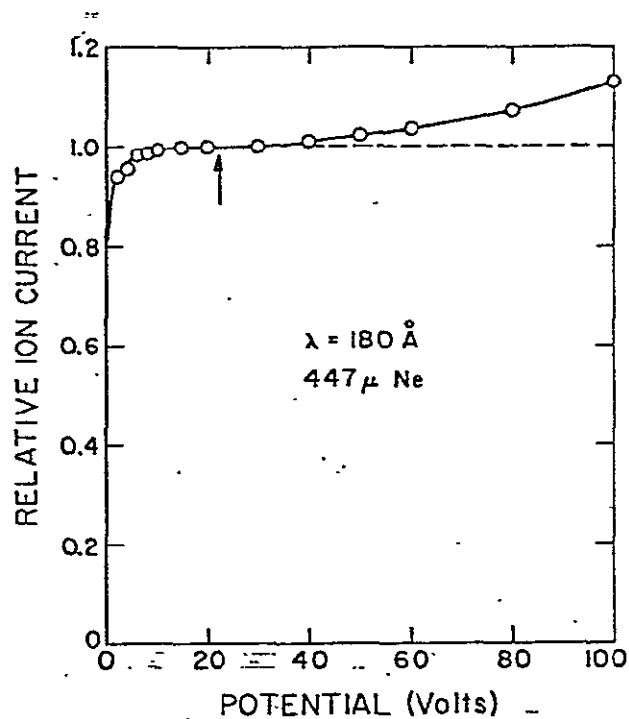


Fig. 2-4. Ion collection characteristics of the ionization chamber. The measurements were obtained at the University of Wisconsin Synchrotron Radiation Center with an incident wavelength of  $180 \text{ \AA}$  and a neon pressure of  $0.447 \text{ torr}$ . The plateau in the 10-40 volt region indicates 100% efficiency in ion collection. At higher voltages secondary ionization occurs by the accelerated electrons. A voltage of 22.0 volts (indicated by arrow) was used during flight.

### Prior Flight Results

An experiment similar to that proposed here was launched on an Aerobee 200 research rocket NASA 26.041 US/UA on 27 Nov 1974 at 18<sup>h</sup>00<sup>m</sup>UT (11<sup>h</sup>00<sup>m</sup> LST) from White Sands Missile Range, and attained a peak altitude of 295 km. An Ames Research Center SPARCS pointing control oriented the payload toward the sun. The solar zenith angle was 55°. A total of eleven pressure cycles were recorded. Results obtained just after apogee were shown in Fig. 2-2. A slowly varying ionospheric component of ~15% relative magnitude was observed and subtracted from the raw data.

The 10.7 cm radio flux on the day of the flight was  $F_{10.7} = 90.8$  in the customary units while the Zurich sunspot number was  $R_z = 27$ . The local exospheric temperature calculated from Jacchia's (1971) formulation was  $T = 839^\circ\text{K}$  and the observed altitude variation is in good agreement with densities predicted by Jacchia's (1971) model. At apogee the slant path optical thickness is calculated to be 0.021 with uncertainties in the absorption cross-section for atomic oxygen and the atmospheric model introducing an estimated error of  $\pm 0.007$ .

The plateau saturation current obtained from the measurements at apogee is  $47.5 \pm 0.5$  pA. Applying minor corrections (discussed later) and normalizing to 1 AU, the resulting solar flux in the 50-575 Å is found to be  $2.8 \times 10^{10}$  photons/sec-cm<sup>2</sup> with a possible error of  $\pm 15\%$ . These and other measurements are shown in Fig. 2-5. The relatively large uncertainty (15%) is due to the influence of photoelectrons which arises when high pressures are used. The proposed instrument will work at much lower pressures and longer path lengths.

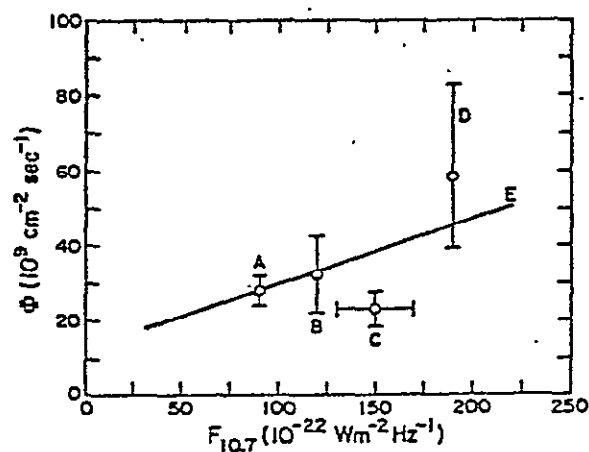


Fig. 2-5. Comparison of measured values of the total solar flux in the 50-575 Å region with solar radio activity at 10.7 cm.

A: Present measurements      B: Heroux et al. (1974)      C: Hinteregger (1970)  
D: Timothy et al. (1972)      E: Variation of the solar ultraviolet with the 10.7 cm flux obtained from the regression analysis of Chapman and Neupert (1974) and re-expressed as a photon flux and normalized to the present measurements.

The present measurements, which were obtained during a period of low solar activity, are a factor of 1.2 higher than Hinteregger's (1970) values for medium solar activity. It may be premature to make a more detailed comparison on the basis of a single flight which investigates a more limited spectral region and was performed at a different level of solar activity. However, the spectral region investigated here contains ~75% of the solar flux which produces the ionospheric F-region and further the variation of short wavelength flux with solar activity (specifically, the 10.7 cm radio flux) has been investigated (Chapman and Neupert, 1974) and an extrapolation can be performed with some confidence. The results are shown in Fig. 2-5 along with the flux measurements of Heroux et al. (1974), Hinteregger (1970), and Timothy et al. (1972). The solid line shown in the Figure is from the regression analysis of Chapman and Neupert (1974) (their Table 5) reexpressed in terms of photons/sec-cm<sup>2</sup> and normalized to the present data. It can be seen that for medium solar activity these results give a solar flux greater than Hinteregger's value but in excellent agreement with the later values of Heroux et al. (1974) and in agreement (within the limits of error) with those of Timothy et al. (1972).

## Error Analysis

The possible sources of errors in the proposed measurements can be categorized into two broad areas: the first area involves fundamental non-ideal absorption characteristics of the neon gas which are unavoidable but can be minimized with appropriate design, while the second area is concerned with engineering matters such as the stability of electronic circuit components and gas purity. We consider first the errors due to the non-ideal ultraviolet atomic absorption properties of neon.

Although neon is the best gas for ionization chamber measurements, it is not a perfect ultraviolet ionization chamber gas since the absorption cross section decreases at the shorter wavelengths, becoming optically thin, and therefore not absorbing all of the incident flux. In the same wavelength region, small departures from unit ionization yield occur due to multiple electron ionization, the production of ionizing metastable states and ionizing radiation, and the effect of energetic photoelectrons which can cause secondary ionization. These effects are small, furthermore the increased ionization yield at the short wavelengths partially compensates for the decreasing absorption cross section. Numerical values are given below.

During the pressure cycling of the proposed experiment (and the prior rocket instrument) the optical depth of the gas is sufficient to absorb >99% of the radiation between threshold and 180 Å. This accounts for ≈90% of the total solar flux below 575 Å. Absorption at shorter wavelengths is somewhat less, but the net result is that >97% of the flux in the 50 Å-575 Å region is absorbed. Below ≈50 Å the ion chamber becomes insensitive due to the decreasing neon absorption cross section.

The onset for double ionization is 62.6 eV (198 Å), and neon does show a small amount of double ionization at higher energies. The cross section is small, however, resulting in an increase in the ionization yield of only 3% at 150 Å (Samson and Haddad, 1974). From Samson and Haddad's measurements and using a representative solar flux distribution (Heroux et al., 1974), the total correction for double ionization is found to be 0.7% and estimated to be correct to ±0.3%. The possibility of simultaneous ionization and excitation by photoionization of an inner 2s electron must also be considered. This process leaves the ion in an excited state which can produce further ionization, either through inelastic collisions (Penning ionization) or by emission of an ionizing photon ( $\lambda = 462$  Å). The threshold for this process is 48.4 eV (256 Å). Wuilleumier and Krause (1974) and Samson and Gardner (1974) have measured the ratios for 2s and 2p photoionization. At 243 Å the s to p ratio is 2.1% and increases with energy, becoming 12% at 209 Å. These measurements, in conjunction with the solar flux distribution of Heroux et al. (1974), lead to a (2.4±1.0)% correction for the simultaneous ionization and excitation process.

The photoelectron contribution is somewhat more difficult to evaluate since it depends upon the probability of secondary ionization which in turn



depends upon the gas pressure employed and the geometry of the cell. The proposed experiment will use a long, narrow cell and low pressures. At peak pressures of 150  $\mu$ Torr and with a mean radius of 0.5 cm in the front region of the cell (where most of the absorption occurs) then the probability of a 50 eV photoelectron causing secondary ionization is  $\approx 0.08$ . Since  $\approx 35$  eV is lost in each electron-ion pair, an initial 50 eV electron will produce  $0.08 \times 50 / 35 \approx 0.11$  secondaries. Since it is only the very short wavelength region, where there is relatively little flux, that causes this secondary ionization process, the contribution to the total signal is small. A detailed calculation using representative solar spectra (Heroux, 1974) leads to a  $\pm 2\%$  correction.

The combination of all of the above effects yields an estimated net 4% reduction that must be applied to the measurements. The combined uncertainties are  $\approx 3\%$ . An accurate correction factor will be determined experimentally and it is anticipated that the above uncertainty can be reduced somewhat.

In terms of engineering parameters which introduce uncertainties in the measurements, we identify the following areas: (1) measurement of the area and stability of the entrance aperture, (2) the geometry of the ion collection electrode as it relates to energetic photoelectron collection, (3) secondary electron emission from the electrodes, (4) gas purity, and (5) the stability of the ion current electrometer. These are considered below.

The entrance aperture can be measured to certainly much better than 0.3%. One must also monitor the temperature of the aperture plate so that any necessary thermal expansion effects can be incorporated.

It is possible that some photoelectrons possess enough energy to surmount the applied potential and be collected by the ion electrode. For that reason, this electrode is made small in order to present a small solid angle to the emitted photoelectrons. The relative solid angle is  $\approx 2.5\%$  and roughly 40% of the photoelectrons will be produced with a large enough velocity component to be collected. It is therefore estimated that photoelectron collection is 1% or less of the total. The emission of secondary electrons at the ion collection electrode by ion impact has been shown by Gardner and Samson (1974) to be less than 1%.

Energetic electrons which strike the walls can cause secondary emission. In general, the yields and energies of secondaries are too small to cause subsequent ionization; but nevertheless the walls will be coated with a material with a low secondary emission coefficient.

The influence of gas purity is quite insignificant if one uses research grade gas with impurity levels of a few ppm. It is only at impurity levels several thousand times greater that errors at the percent level would be introduced by gas impurity.

Of much more concern is the gain stability of the ion current electrometer, in particular the feedback resistor. The experiment will use properly aged highly stable resistors with quoted stabilities of better than 0.1% per 1000 hours. This corresponds to <1% change per year. In addition, the gain will be monitored using a high stability current source. The current source will use a ramp voltage generator and a stable glass capacitor to inject current into the electrometer system. The fundamental accuracy limitation is the ramp voltage, which can be measured by the rocket data system to 0.5%.

Considering all of the above effects, a conservative absolute error estimate is  $\pm 5\%$ , which probably can be improved somewhat.

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### Mechanical Design

The geometry of the ionization chamber is determined by the requirements of maximizing the amount of radiation absorbed (i.e., maximizing the pressure-path length product) while at the same time minimizing the probability of generating secondary electron-ion pairs by photoelectron excitation (i.e., minimizing the pressure-radius product). This dictates a long narrow ionization chamber. Fortunately, solar radiation is highly directional so that one can construct an ionization chamber with a large length to diameter ratio. In order to minimize the operating pressures the cell needs to be made as long as is practical. For the proposed experiment we chose a length of 1.5 m (~60") and a tapered geometry with an angular divergence of  $0.75^\circ$ . The entrance aperture is chosen to be circular with a diameter of 1 mm as was used in previous experiments. The expected ion currents are  $\sim 0.5-1 \times 10^{-10}$  amperes. A schematic illustration of the proposed instrument is shown in Fig. 2-6:

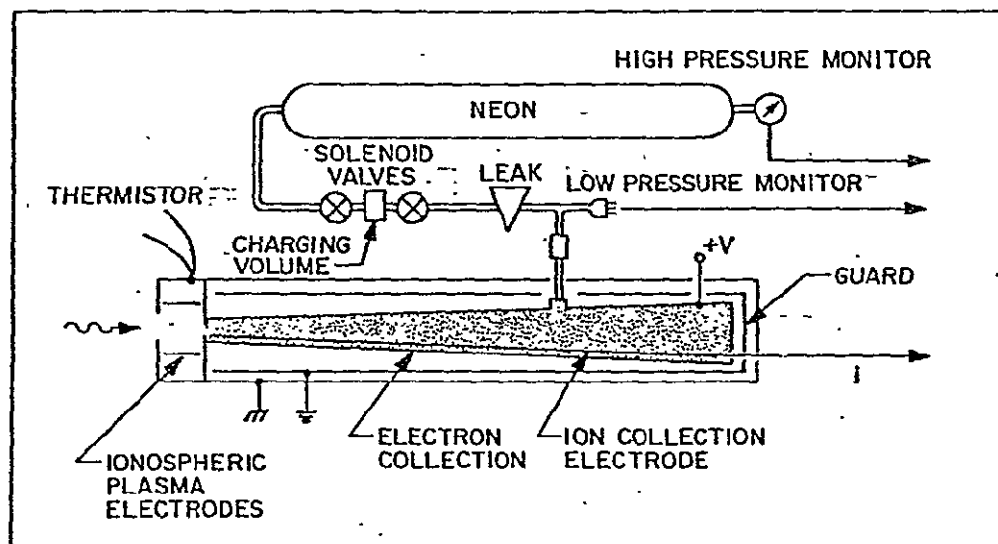


Fig. 2-6. Block diagram of the proposed rare gas ionization chamber. Neon gas is introduced into the ionization chamber by first discharging a small amount from the cylinder into a charging volume. A second valve is then opened which charges the ionization cell to  $\sim 100$  mTorr, with subsequent escape through the entrance aperture. Radiation enters the entrance aperture, producing one ion per absorbed photon. Since the cell is operated in total absorption with 100% ion collection, the measured ion current provides an accurate measure of the solar extreme ultraviolet flux.

The neon supply is a 6 cm x 100 cm stainless steel cylinder with a volume of 2.8 liters. If the pressure is 3 atm and the ionization chamber enclosure volume is 1 liter, then the available number of pressure cycles is  $\sim 3 \times 760 \times 2.8 / 0.1 \times 1 \sim 6 \times 10^4$ . It is anticipated that only a small fraction of the available gas will be used if measurements are taken at intervals of once or twice per minute. The additional capacity insures that the pressure profile will not change with use and allows for the possibility of leaks.

The pressure cycling will occur as follows. Upon command a valve will open charging a fixed volume (see Fig. 2-6) to the neon tank pressure. This fixed charging volume is determined largely by the valve dead volume. After the first valve closes, the second valve opens, filling the ionization cell with neon which then escapes by effusion through the entrance aperture. The time constant for gas escape is 5 sec so the entire pressure cycle will take approximately 20-30 sec. During that interval, ion current measurements should be taken at a rate of  $\sim 5 \text{ sec}^{-1}$ .

A pressure sensor will be used to monitor the neon supply pressure while a thermocouple gauge will measure the ionization chamber pressure. In previous rocket experiments we have successfully used both thermocouple gauges and radioactive ionization pressure gauges. While the latter type is more stable, it can introduce uncertainties due to the production of ions. Various temperature monitors will also be included. Of particular importance are the aperture plate temperature and the temperatures of the electrometer amplifier and reference current source.

Although ionospheric ions are unaffected by the addition of gas into the chamber and give only a slowly varying DC background of small magnitude, nevertheless, the ionospheric plasma will be collected by electrodes before entering the chamber.

### Physical Description

The ion chamber is a very simple instrument so only a short description is necessary. The instrument will be constructed in a single module with a length of 60" and 5" in both width and height. The packaging concept is shown in Fig. 2-7.

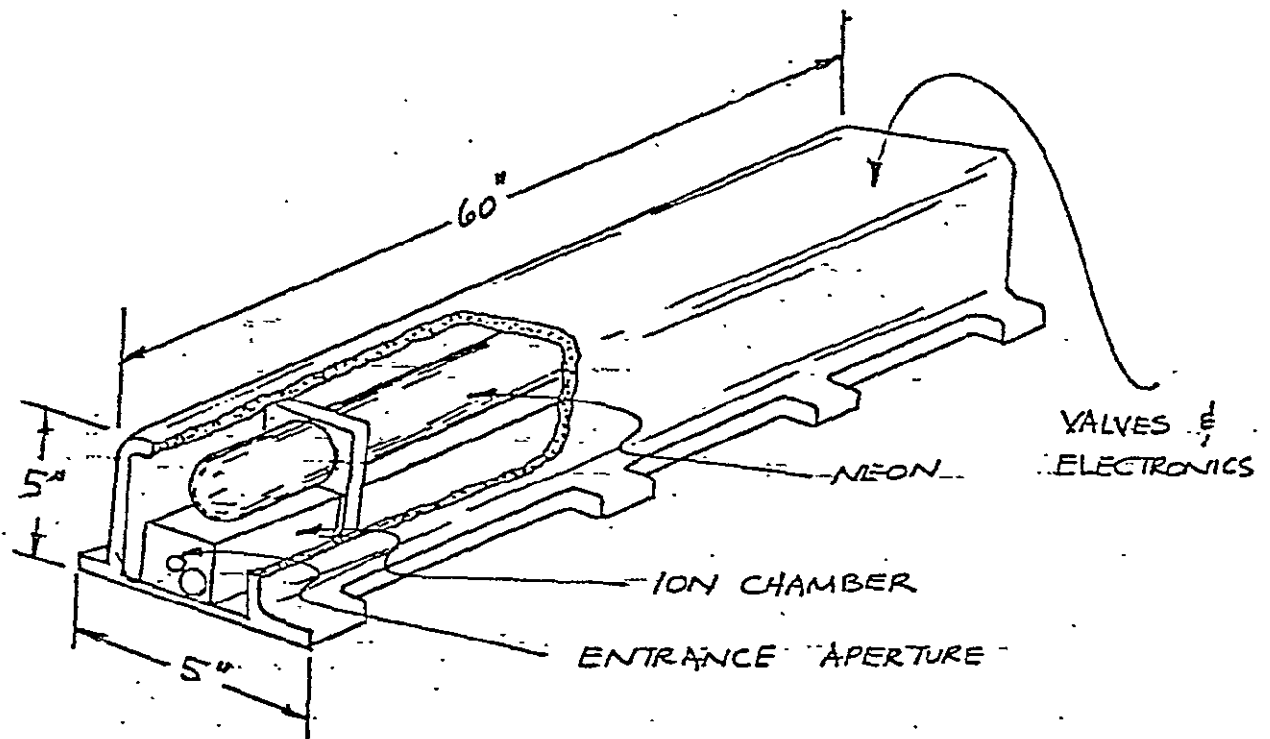


Fig. 2-7. Instrument Packaging Concept

The long axis points toward the sun during the  $\sim 1$  min flux measurement. An optical reference will be attached to the front face for instrument alignment. It should be noted that both the alignment and solar pointing accuracy requirements are not critical since the field-of-view of the experiment is  $3/4^\circ$ . The  $1/2^\circ$  solar diameter requires combined alignment and pointing accuracies of only 7 minutes of arc.

The ionization cell and housing will be constructed of aluminum with a stainless steel ion collection electrode. The wall of the chamber will be fabricated in two segments attached by stainless steel dowel pins and screws. Tapered  $90^\circ$  channels will be milled along the length of the segments to form the ionization chamber itself. A slot will be milled along one of the faces to allow insertion of the ion collection electrode. This electrode is

attached to a guard at signal ground in order to minimize leakage currents. A cross section of the ionization chamber is shown in Fig. 2-8.

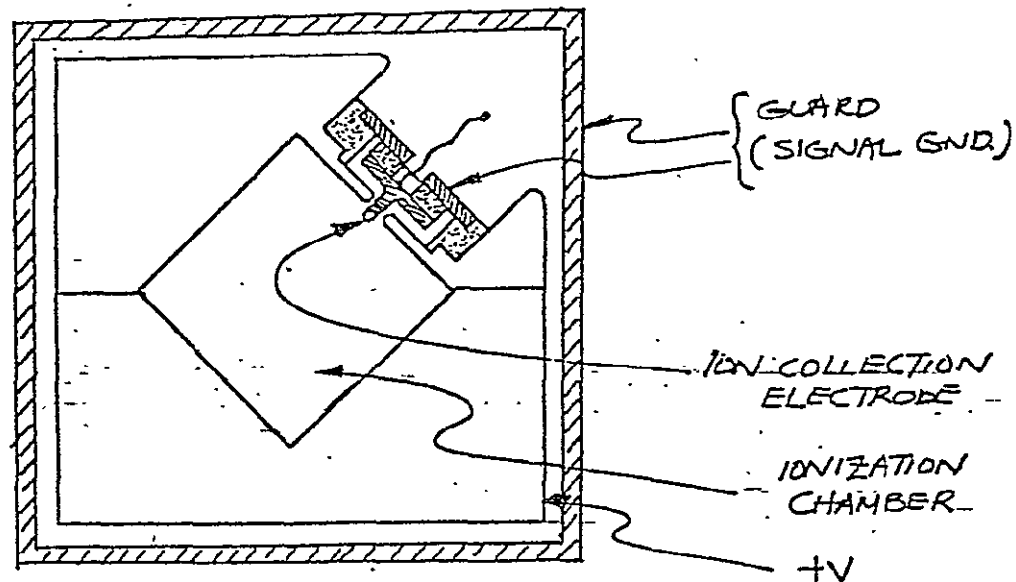


Fig. 2-8. Cross section of the ionization chamber.

The walls of the ionization cell will be coated with platinum black in order to reduce secondary electron emission. The rear surface, also coated with the same material, will be demountable so that one can attach standard photo diodes and transfer standards and also alignment fixtures to align the reference mirror normal to the optical axis.

### Electronic System Design

The electronic system for the proposed experiment is quite simple. The most important aspects of the system are the ion current electrometer and reference current supply used to verify its stability. Other functions include valve drivers, power supplies, temperature monitors, and pressure gauge electronics. The majority of these systems have been already designed and flown on previous experiments. A simplified block diagram of the present instrument is shown in Fig. 2-9.

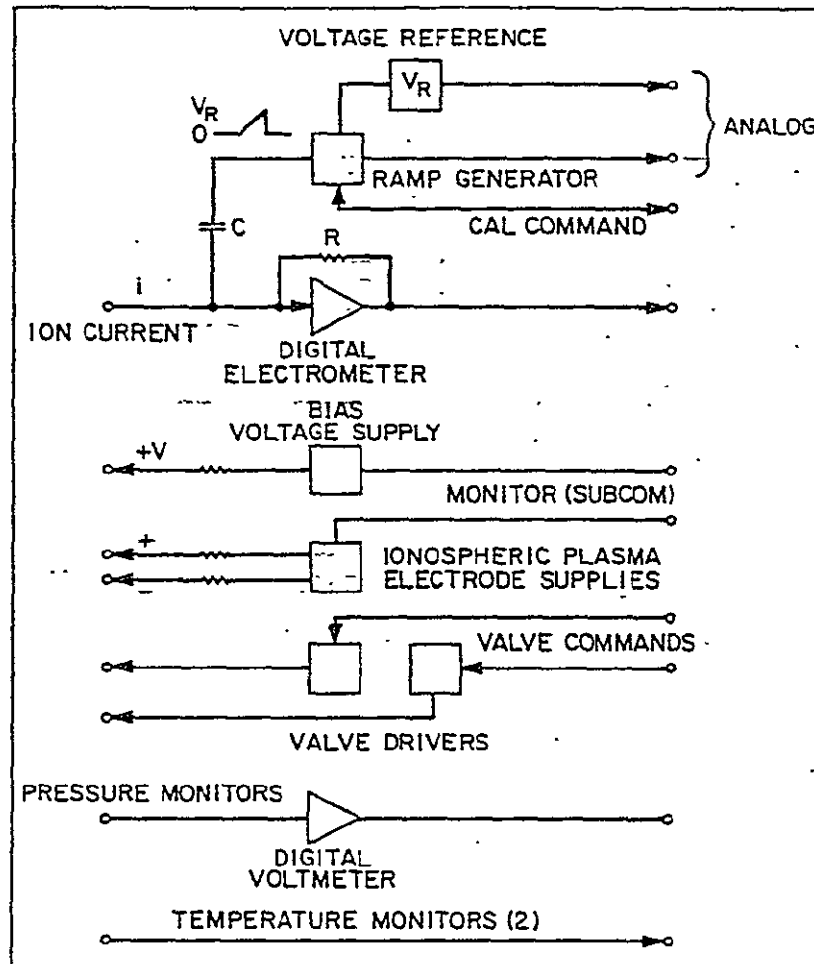


Fig. 2-9. Simplified block diagram of the proposed experiment showing the major subsystems.

The ion current measurement system is a digital electrometer which feeds back pulses of charge to equalize the input current. The average rate of the pulses is proportional to the input current. The dynamic range of the electrometer is  $6 \times 10^4$  while a current range of up to 2.5 nA

### 3. OZONE PROFILE DETERMINATION

#### Scientific Background

The fragility of the ozone shield and its possible modification have recently been recognized, and are of considerable concern. There are three areas of interest: ozone photochemistry, dynamics and transport, and possible secular changes.

Ground-based measurements have been fairly successful in determining gross seasonal and latitudinal variations. Nevertheless, they lack the spatial or temporal resolutions required for a comprehensive study of ozone and its influence on the surface weather and climate. Furthermore, the standard instrumentation (the Dobson spectrometer) is being discontinued. Future ozone monitoring and further understanding of the stratosphere will surely come from orbiting experiments. Thus, there is both scientific motivation and a void to be filled with satellite ozone experiments; the only question being the optimum choice of experiments and instrumentation. A number of different techniques utilizing either a UV or a thermal IR band of ozone have so far been used. The three most successful of them are the Backscatter Ultraviolet (BUV) experiment, (Heath et al., 1973) the Infrared Interferometer Spectrometer (IRIS) experiment, (Prabhakara et al., 1973) and the Limb Radiance Infrared Radiometer (LRIR) experiment (Gille, 1976). However, while providing the total ozone and its vertical distribution above 30 km altitude, the BUV experiment cannot probe the altitude region 8-30 km, an unfortunate circumstance since it is probably the most important region for ozone studies. On the other hand, in order to determine the total ozone amount, the IRIS experiment must assume models of the stratospheric distribution. The result therefore depends on the applicability of such models to the experiment conditions. The proposed ozone experiment will complement the BUV experiment in being able to sense altitudes below 30 km. It will also provide an alternative to the LRIR experiment by avoiding some of the complications associated with the use of infrared radiation such as the need to obtain simultaneously the vertical temperature profile, and the necessity to work with weak signals and cooled detectors.



Table 3-1

EXPERIMENTS FOR REMOTE SENSING OF ATMOSPHERIC OZONEA. ULTRAVIOLET

| <u>Investigator</u>   | <u>Type</u>                            | <u>Vehicle</u>             | <u>Parameters Obtained</u>                                                      |
|-----------------------|----------------------------------------|----------------------------|---------------------------------------------------------------------------------|
| Iozenas et al.        | Atmospheric Radiance<br>(Spectrometer) | Kosmos                     | Total O <sub>3</sub> above 20, 25, 30, 35, 42 km, neglects Rayleigh attenuation |
| Brinkmann et al.      | Atmospheric Radiance<br>(Spectrometer) | Sounding<br>Rocket         | Vertical distribution using crude O <sub>3</sub> model                          |
| Rawcliffe and Elliott | Atmospheric Radiance<br>(Photometer)   | Satellite<br>(AF)          | Total O <sub>3</sub> above 35 km                                                |
| Anderson et al.       | Atmospheric Radiance<br>(Spectrometer) | Satellite<br>(OGO)         | Vertical ozone distribution in upper stratosphere                               |
| Heath et al. (1973)   | Atmospheric Radiance<br>(Spectrometer) | Satellite<br>Nimbus, Tiros | Vertical distribution using crude model, total ozone                            |
| Weeks and Smith       | Solar Occultation                      | Rocket                     | Distribution above 50 km                                                        |
| Hays and Roble        | Stellar Occultation                    | Satellite<br>(OAO-2)       | Distribution in 60-100 km region                                                |

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|                          |                                           |                       |                                                                |
|--------------------------|-------------------------------------------|-----------------------|----------------------------------------------------------------|
| Prabhakara et al. (1973) | Absorption at<br>9.6 Microns (IRIS)       | Satellite<br>(Nimbus) | Total ozone (imprecise owing to pressure, temperature effects) |
| Gille et al. (1976)      | Limb Radiance at<br>9.6 Microns<br>(LRIR) | Satellite<br>(Nimbus) | Vertical distribution of O <sub>3</sub> above clouds           |

### Proposed Vertical Profile Measurements

The vertical profile of ozone will be determined by the altitude dependence of visible radiation from the limb. The procedure rests on two important physical facts (i) atmospheric absorption in the ozone Chappuis band is much larger than attenuation by either aerosol absorption or scattering from both gases and aerosols; and (ii) that absorption of light originating in the atmosphere (by scattering of solar light) and traversing tangential paths through the atmosphere is large enough to be readily measured and yet small enough that one can probe far below the ozone peak.

Limb intensity profiles will be obtained in two wavelength intervals, one centered at the Chappuis band maximum ( $\sim 6000 \text{ \AA}$ ) with the second located at a nearby wavelength ( $\sim 5300 \text{ \AA}$ ) where Rayleigh and aerosol extinction (= scattering + absorption) are nearly equal, but with much less ozone absorption. The latter wavelength gives the composite atmospheric extinction profile, while  $6000 \text{ \AA}$  data yields this and the added influence of ozone absorption. For light originating at  $15 \text{ km}$  altitude, the ozone absorption is roughly a factor of five greater than other absorption processes and the slant-path optical thickness of ozone is approximately unity.

The present method is very favorable to lower-atmospheric measurements since the majority of the observed radiation originates at low altitudes and the differential path lengths (per-unit change in altitude) are greater at the lower altitudes. For example, a tangent ray originating at  $15 \text{ km}$  traverses  $\sim 6$  times more distance in going from  $15$  to  $16 \text{ km}$  than from  $25$  to  $26 \text{ km}$ , consequently effects due to low-altitude ozone are enhanced relative to upper atmosphere ozone.

The weighting functions (or intensity contribution functions) are shown in Fig. 3-1 along with the corresponding weighting functions for the BUV instrument. It is to be noted that the functions are more sharply peaked and occur even below the ozone maximum, in distinct contrast to the BUV experiment.

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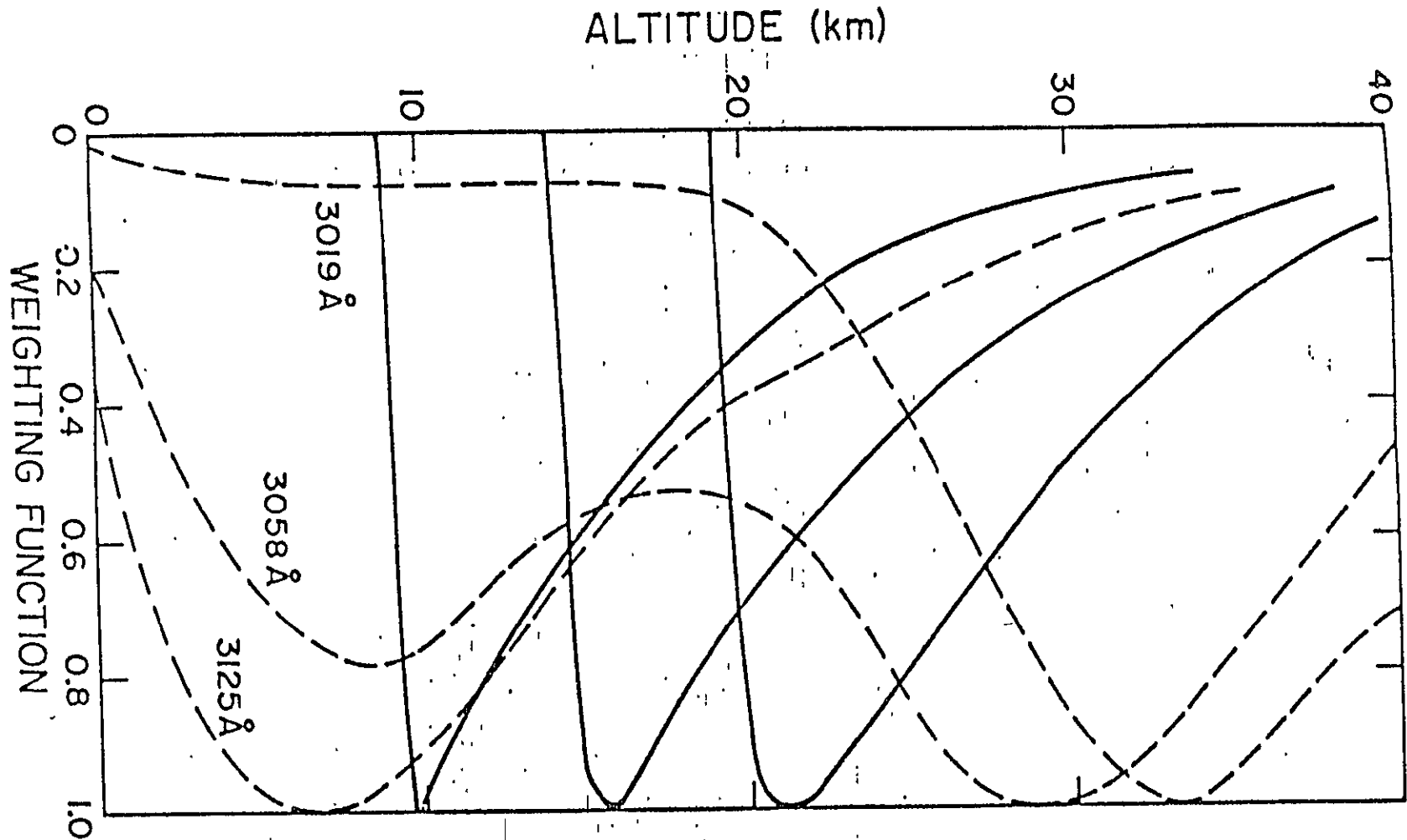


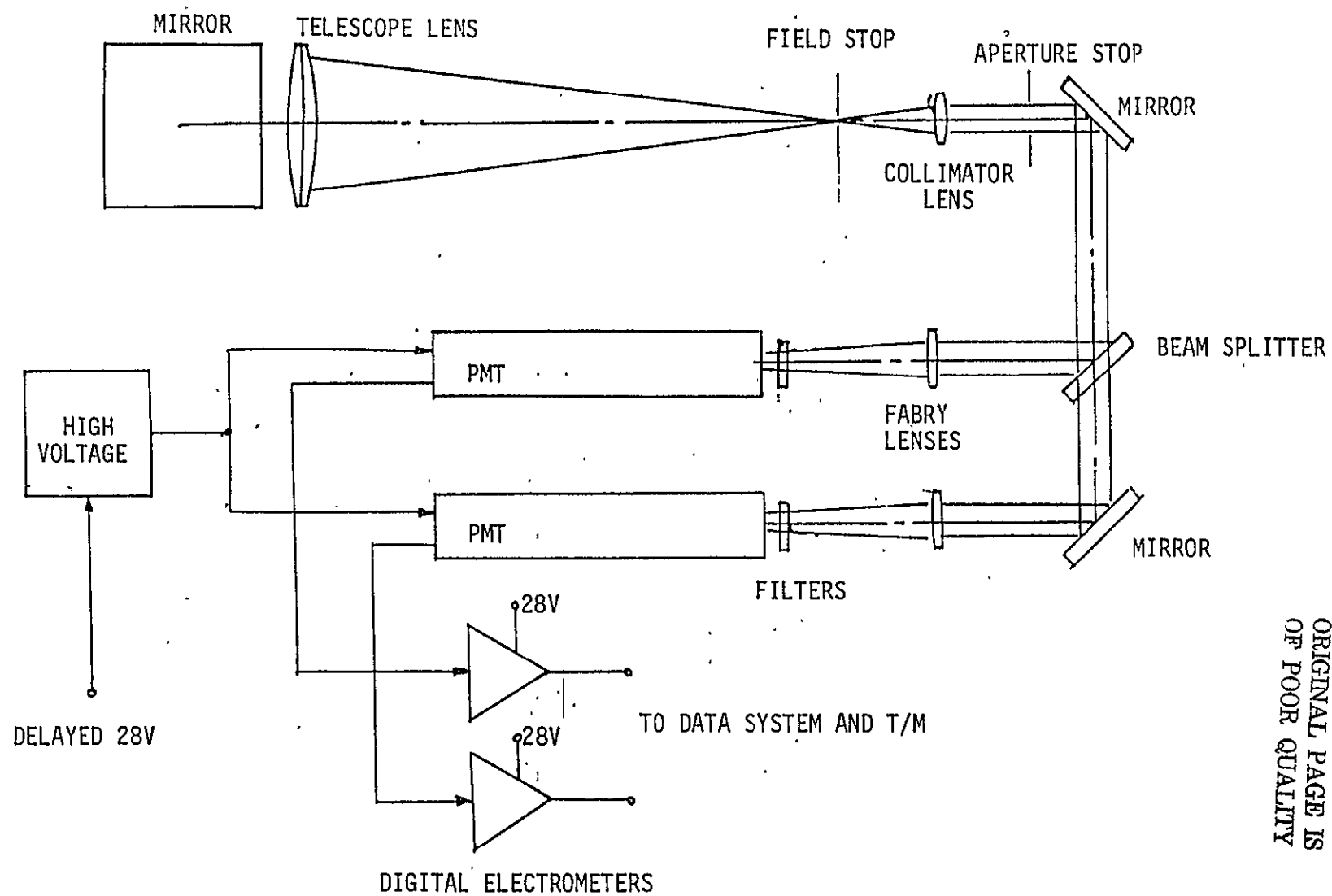
Figure 3-1. Weighting Functions for Ozone Profile Measurements.

The solid curves are for the visible ozone experiment suggested here and correspond to tangent altitudes of 10, 15, and 20 km. The dashed curves are the weighting functions of the UV instrument at three different wavelengths.

### Instrumentation

The optical and electronic design for the ozone measurements are quite simple. The optical system is a two channel photometer with a collimator lens, field defining aperture, beam splitters, filters, and photomultiplier detectors. The limb scan will be accomplished with either the rocket motion or a rocking motor. Physical dimensions of the photometer are 10" x 6" x 3" and the weight is estimated at 5 lb.

The electronic data system will use proven pulse amplifier discriminators and a standard digital data system. A block diagram of the optical and electronic system is shown in Fig. 3-2.



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Figure 3-2. Block diagram of the ozone photometer

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